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AMERICAN MACHINIST

A PRACTICAL JOURNAL OF MACHINE CONSTRUCTION.

ISSUED WEEKLY BY THE HILL PUBLISHING COMPANY,

Vol. 31. 505 PEARL STREET, NEW YORK. No. 13.

Index to Advertisers and Classified Index Following Reading Matter.

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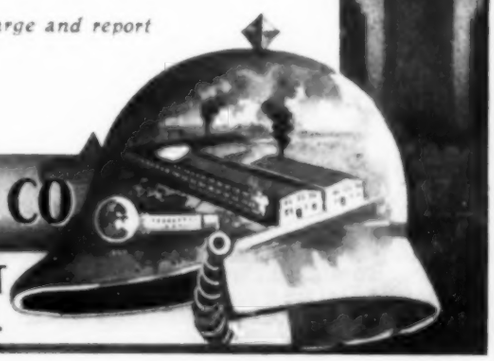

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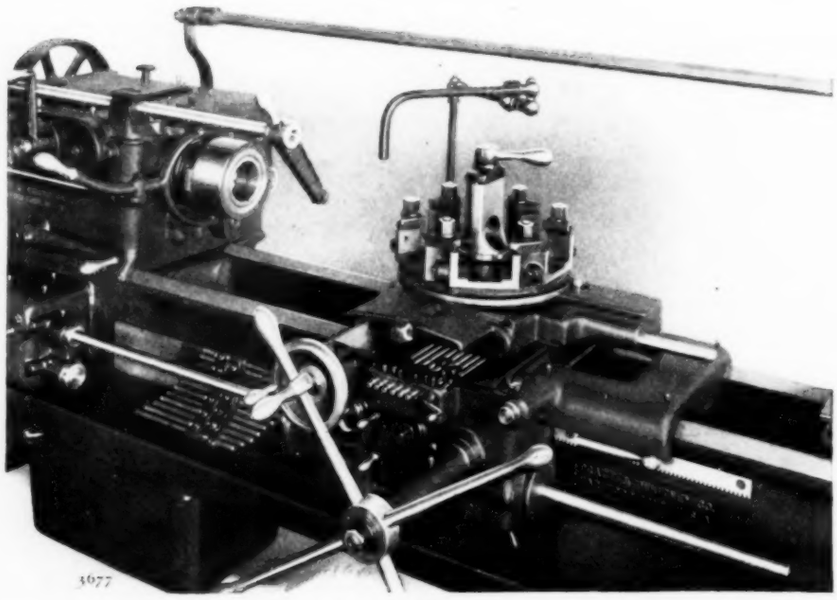

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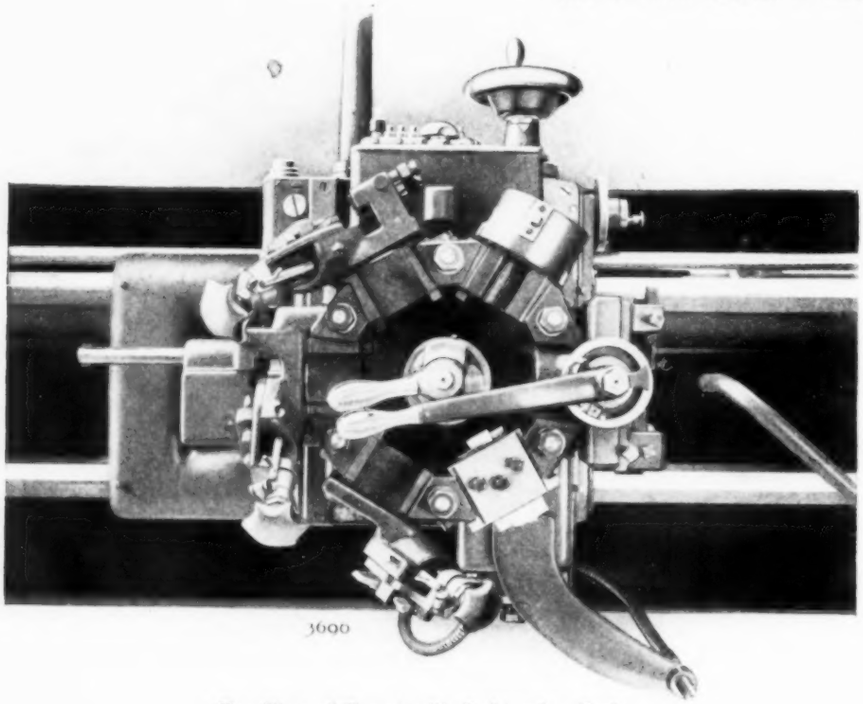
View of Turret Showing 12 Longitudinal and 8 Cross-feed Stops.



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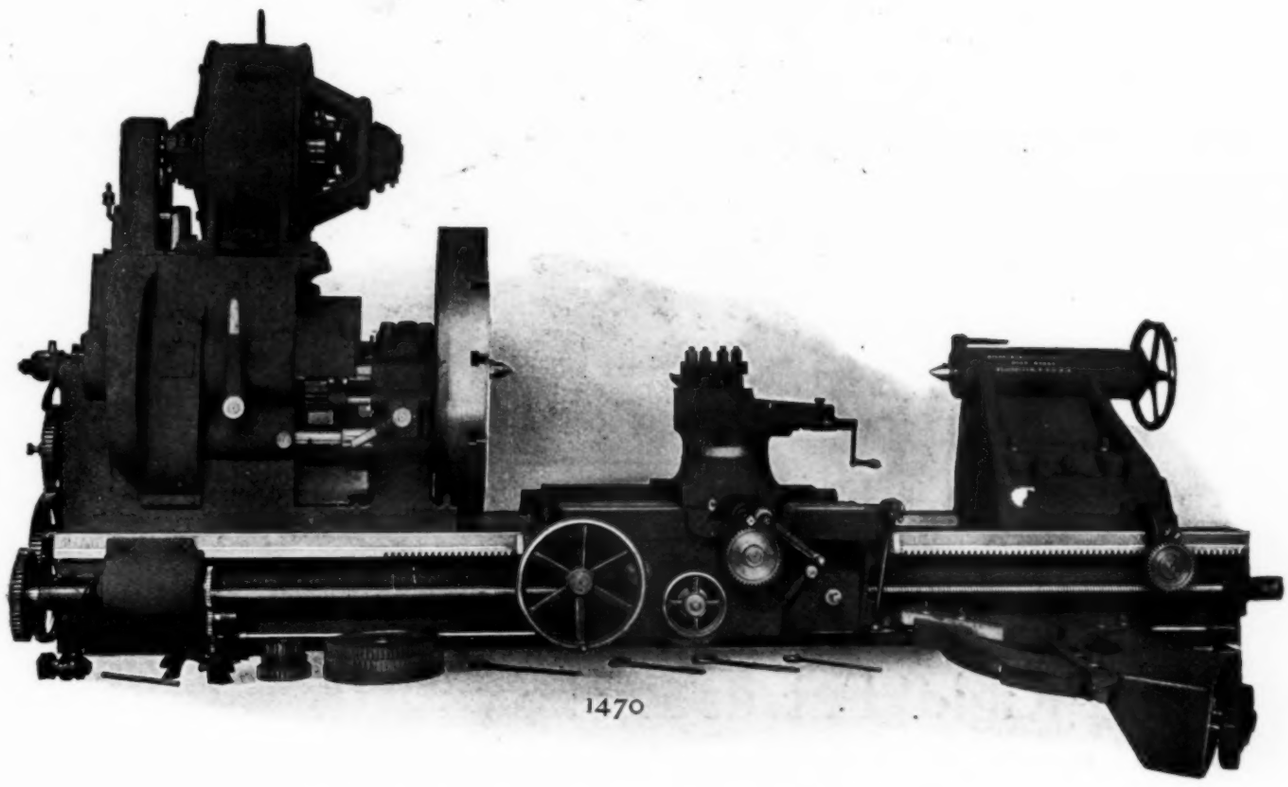

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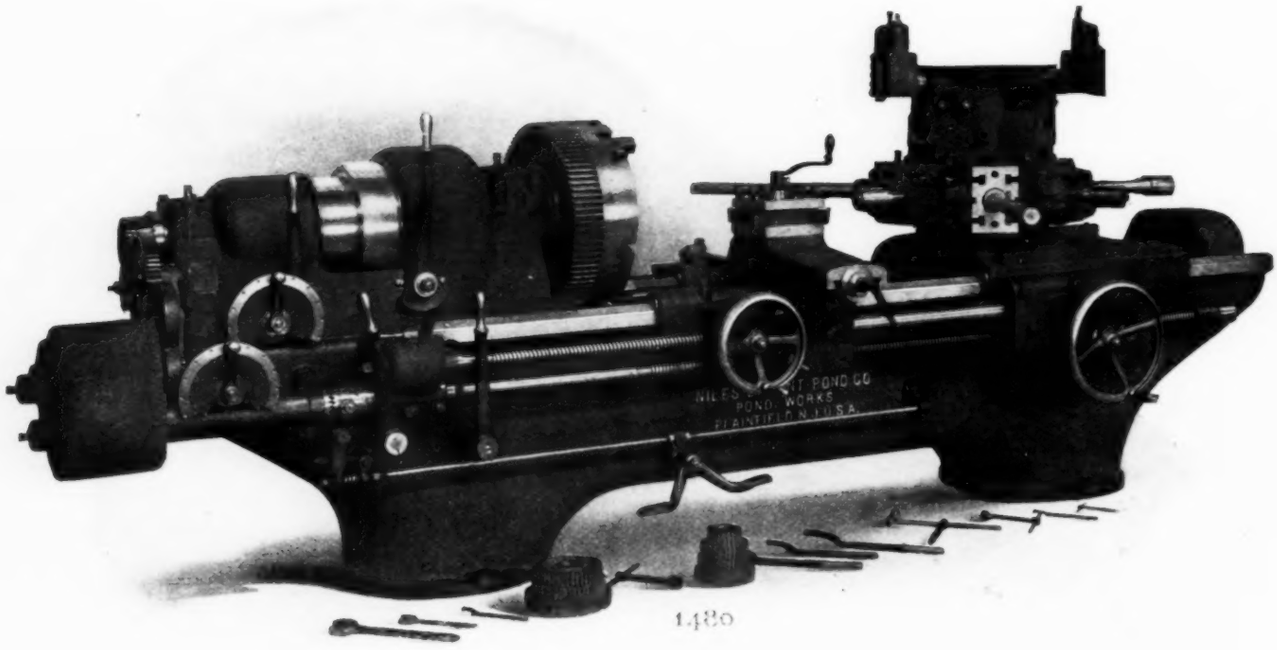

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Grinding vs. Cutting by Emery Wheels

Comparison of Conditions, Power, Speeds and Time Necessary to Remove Metal by Grinding under Normal and Abnormal Conditions

BY C. H. NORTON*

There seems to be a good deal of misunderstanding in the mechanical world as to what is going on when a grinding wheel is removing stock from work. This expression is often heard: "This wheel cuts; it does not grind;" the intention being to impress the reader or hearer with the thought that that particular wheel has in it some virtue of cutting that other grinding wheels do not have.

It is, of course, true that many wheels cut very poorly, so also do many tools. Because some of the cutting particles of grinding wheels are blunt, or even round, does not prevent their cutting.

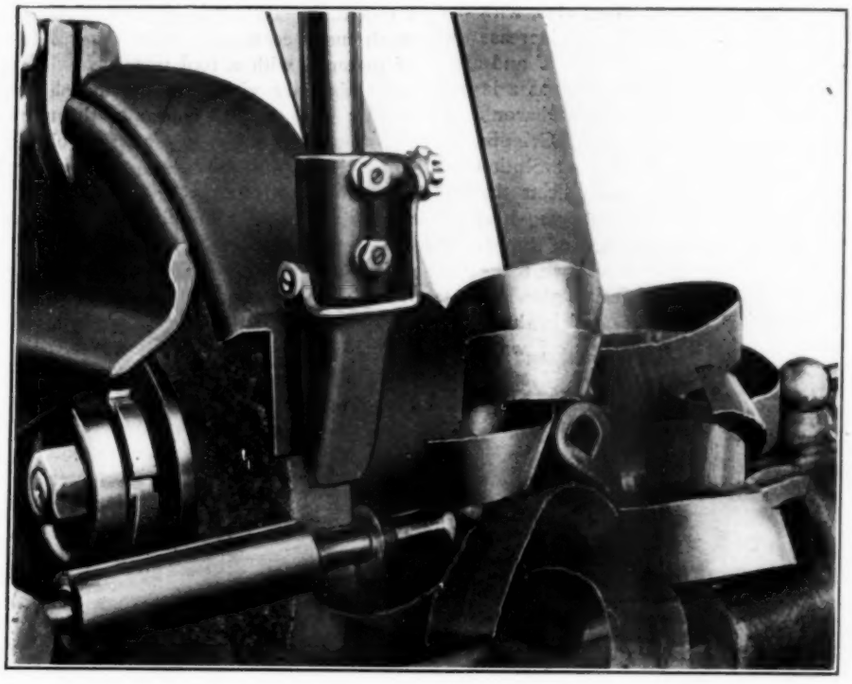


FIG. 1. PRODUCING A RIBBON BY ABNORMAL GRINDING

We can all remember when we could not conceive of a lathe tool as capable of cutting unless it had a *sharp* and raking *edge;* but modern high-speed steels have shown us that tools without *sharp edges* or *sharp points* cut off the greatest quantity of chips in the shortest time.

The quality of these steels for cutting at high speed is the secret of their success; so with grinding wheels. Some are made of material that cuts better than that of which others are made. All cut best at higher speed than high-speed steel tools, and both cutting wheels and high-speed steel tools many times have blunt edges.

Many people, however, use grinding wheels that have so hard a bond holding the cutting particles together or so fine particles that the wheel is so dense that there is no possibility for the cutting particles to project enough to cut, and there is certainly no room for chips if they were removed. Such wheels, however, *last longer* than good ones. Such people are doing precisely what the lathe operator would be doing if he covered the cutting point of the tool with solid steel, allowing the point to project only 0.0005 inch or so, and then forcing the lathe to remove large quantities of metal in a short time. Result: great heat and great power required, hence great waste. In this manner he could make the tool last a long time at the expense of power, lathe, time. Would we say that all steel tools grind instead of cut because of the action of such a tool?

It is probably true, however, that the great mass of mechanics think of grinding as something apart from cutting. Having spent something over twenty years as a specialist on cylindrical grinding, I have come to know, through that experience, that whether the material is removed by a good grinding wheel or a good turning tool, it is cut just the same. With the grinding wheel the chips are so very small that we do not recognize them as chips without the aid of the microscope. The microscope, however, shows them clearly to be shavings identical with the cuttings from steel tools, except that they are of many different shapes, widths and lengths, because the cutting points of the grinding wheel are of different shapes and angles of clearance. Some have a raking cut, some have a dragging cut. It is, however, still natural for the mechanic to discredit what I have just stated, and regard grinding as something apart from cutting. For this reason a photograph like Fig. 1 becomes at once interesting to him; and, if he is uninitiated in the art of cylindrical grinding, he naturally supposes, when seeing this photograph, that great advances have been made in cylindrical grinding and at last his ideal way of removing material has been found with the grinding machine. He can see clearly the long, ribbon-like chips or shavings that are removed by the wheel. He also at once becomes interested in the machine and wheel that has produced them.

Photograph No. 1 is of a Norton grinding machine in the act of removing ribbon-like chips from 35-point carbon steel, and the depth of cut can be seen in the photograph, the wheel being forced directly toward the axis and cutting its full width. This photograph was made during some tests to establish the facts in regard to this phenomenon. The tests were made very thoroughly, many different wheels, speeds, feeds, etc., were used, instruments were connected with the electric motor for measuring the power, and everything was done to insure scientific investigation into the facts. These tests determined the following facts:

Viz., that almost any kind of grinding wheel, whether good or bad, can be made to produce these ribbon-like chips.

The poorer the grinding wheel, the heavier will be the ribbon chip which is removed in a given time, but the greater will be the power required.

The better the grinding wheel, the lighter will be the ribbon chips and the horse-power required will be proportionately less.

The slower the revolution of the work and the less the amount of material removed per minute per horse-power, the better will the ribbon appear.

The faster the revolution of the work and the more work accomplished per minute per horse-power, the less will the ribbon appear, until it disappears entirely.

With a really good cutting wheel it is most difficult to produce the ribbon.

*The Norton Company, Worcester, Mass.

With a really poor cutting wheel it is most easy to produce the ribbon.

In the test shown in the photograph the total stock removed in the place shown where the wheel is cutting was 2.34 cubic inches.

The cutting time when removing the stock by the ribbon chip method was ten minutes.

The cutting time when removing the same amount of stock by the ordinary method was one minute and 30 seconds.

While the same amount of stock was removed in each case, there was a vast difference in time in favor of the ordinary method. The horse-power consumed was 9.6 during the ten minutes for the ribbon test and 8.8 during one minute and 30 seconds for the regular method of grinding.

The stock removed per minute per horse-power with the ribbon method was 0.244 cubic inch.

For the regular method, 0.1475 cubic inch.

The cost to remove one cubic foot of steel, rating power at 1½c. per horse-power-hour and labor at 30c. per hour, would be, for the ribbon method, $55.10 and for the regular method $8.63.

The quantity efficiency of the ribbon method compared with the regular method was between 15 and 16 per cent. In the case of the photograph, the ribbon chip is only 15 per cent. of the total steel removed.

In order to produce these ribbon chips with a *good* wheel we were obliged to dull the face of it until it was glazed and then to force it into the work so fast that steel would adhere to the face and increase the heating.

It is thus very clear that while these ribbons convey the impression, to those unacquainted with grinding, that some great feat in removing material has been accomplished, in reality it is a step away backward.

It may be interesting to know what is going on between the grinding wheel and the revolving work when this chip is removed in this way. The illustration, Fig. 2, is made after a very careful study of the facts and I am quite sure that this explanation is correct. The work *A* in the case of the photograph was revolving only two revolutions per minute in the direction of the arrow. The wheel was revolving 6000 feet per minute in the other direction. The line of contact or depth of cut was practically the same as that shown in the sketch. The greater part of the material that was removed from the point *B*, where the wheel first comes in contact with the work, to the point *C*, was removed in the ordinary way. From the point *C* to *D* the work was almost at a white heat. Consequently the metal was so soft that, owing to the extraordinary poor condition of the grinding wheel, it was rolled off, very much as a dull milling cutter will roll off a bur when passing over the end of the work. The water flowing on the work prevented the work from accumulating heat and eventually becoming red hot all over. It kept the red-hot point limited to the point *C* to *D*. A slower revolution would increase the size or hight of this red-hot point up to *E*, or higher, according to the speed of revolution. This consequently would give

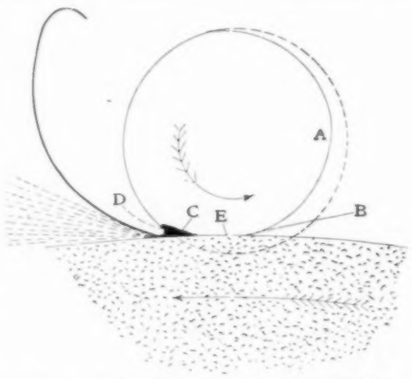


FIG. 2. THE FORMATION OF THE RIBBON

a thicker ribbon at a greater expense of horse-power. A poor wheel also, with the same revolution of work, will increase the heating to a higher point than *C* and consequently make a thicker chip, as a larger proportion of the steel removed would be rolled off instead of cut off. Grinding in this manner with a slow revolution of work, without water, finally heats the entire piece of work to a forging heat all through in the neighborhood of the cutting wheel. In fact, in one test we made the entire piece of work became glowing hot, as though it had been heated in the forge. In this case the chip rolled off was very thick.

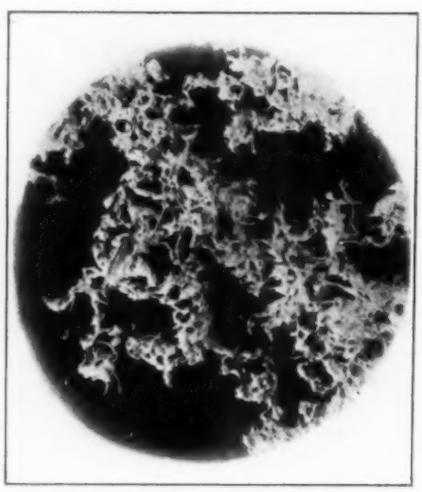


FIG. 3. CHIPS FROM NORMAL GRINDING MAGNIFIED

I should explain that here before any ribbon appears by this process the wheel must grind long enough, under this abnormal pressure and abnormally slow revolution work, to heat the work at the point *C-D*. Consequently a large amount of material is removed before this occurs, cutting quite deeply into the diameter of the work. The poorer the wheel, the sooner will the ribbon appear; the better the wheel, the longer will the ordinary grinding continue before the heating accumulates and the ribbon is formed.

Boiled down, the proposition means that to produce ribbons like those shown in the photograph one must violate all economy in grinding, and grinding becomes abnormally expensive, wear and tear on the machine is abnormal, and the excessive heating calls for a great waste of power.

The result of economical grinding is chips like those shown in the micro photograph in Fig. 3. This photograph was taken from chips caught from normal grinding.

It is not necessarily true that the only way to remove material economically is by tools that make broad chips, visible to the naked eye. It has developed in the last few years that in removing relatively small quantities of material, such as the reduction of work 1/64 inch, 1/32 inch, or 1/16 inch in diameter (where *quality of surface* is considered), the removal of steel with a tool that makes infinitely small chips is much more economical than the removal of material with a tool that makes large chips that are visible to the naked eye; so that while it may appear to the uninitiated, when looking at a photograph like Fig. 1 that the machine and grinding wheel that produces such a result is superior to those that grind in the ordinary way, this is not true and might be exactly the reverse. The machine and wheel that could not produce work any other way would be worthless for removing stock in a commercial way. Indeed, the phenomenon is simply the result of experimenting in an abnormal way with a machine and wheel intended to do practical, commercial work, and reveals nothing indicating either a practical method of removing material or any superiority of the machine or wheel thus used.

Machinery in the Transvaal Mines

The purchases of machinery made during the year ending June 30, 1907, by the Transvaal gold-mining industry were of 20,883 horse-power, of the value of nearly $6,500,000. Exporters may be interested in knowing the kinds of machinery purchased. Among the principal acquisitions were steam winding engines valued at £74,942 (£1 = $4.86); steam engines and compressors, £52,734; electric generators and engines, $48,890; belt conveyers and elevators, £26,334; reduction plant, £57,979; and treatment plant, £60,405. Other items were steel headgear, mechanical excavators, belt conveyers, etc. Altogether the capacity of the machinery and plant erected in Transvaal gold mines and allied concerns at the end of the official year attained the respectable figure of 314,457 horse-power, of an aggregate value of £21,242,843.

High-speed Steel Formed Milling Cutters*

Are Shaped by a Former-controlled Cutter, Heated in a Special Furnace, Revolved in an Air-blast, Ground and Give Long Service

BY DR. H. T. ASHTON

Although the system of manufacture of milling cutters detailed in this paper is suitable for general application, it has been developed more particularly to meet the difficulties of extending the use of high-speed steel to milling cutters of complicated shape, required when cutting to give an accurate finish and a good surface. It is believed that these difficulties have been commonly met with, and that owing to them the general introduction of high-speed steels of the Taylor-White class has, so far, generally proved of less benefit to engineers for milling cutters than for any other form of cutting tool used in engineering workshops.

Perhaps the advantages to be obtained by the use of high-speed steels for such cutters are also not so obvious as they are for the heavy lathe or planer tools, where the almost red-hot chips, that they can be made to produce, appeal to the least observant onlooker. When, however, it is considered that this class of steel not only has the property of keeping a cutting edge for a reasonable time when taking very heavy cuts at a previously unattainable speed, but also keeps its cutting edge when used with a moderate cut and speed for a far longer period than was previously obtainable, its advantages, if applicable to complicated milling cutters, are clearly just as great as for the simpler tools taking the heavy cuts. For, although the nature of the work upon which the cut is taken and the finish required from the cut may not allow, in the case of the milling cutter, any great increase of speed or feed by the use of high-speed steel, and consequently little direct saving upon the time occupied in doing the work, as in the cases of the other classes of tools, yet an equally important saving is effected upon the cost of supply of the tools themselves. The milling cutter is the most expensive of all the tools used by engineers in cutting metals. In the simplest milling cutter the cost of workmanship so largely exceeds the cost of material that a moderate increase of life obtained by improvements in the raw material far outweighs a considerable increase in its original cost, provided that there is sufficient work in sight for the cutter to insure its being fully employed for its maximum possible life. Perhaps it is this ruling condition which has led to somewhat less attention being paid to the application of these steels to milling cutters in general engineering workshops than to other cutting tools. For in these, with the exception of a few simple cutters generally useful for roughing out or for finishing simple profiles likely to recur, it has perhaps generally been more economical to make the cutters from ordinary qualities of tool steel, or even in some cases from case-hardened mild steel; hence the preparation of an elaborate milling cutter from high-speed steel has not received quite the same general attention as the preparation of other cutting tools of maximum endurance.

The case, however, is different in a number of workshops where the interchangeable parts of many classes of ap-

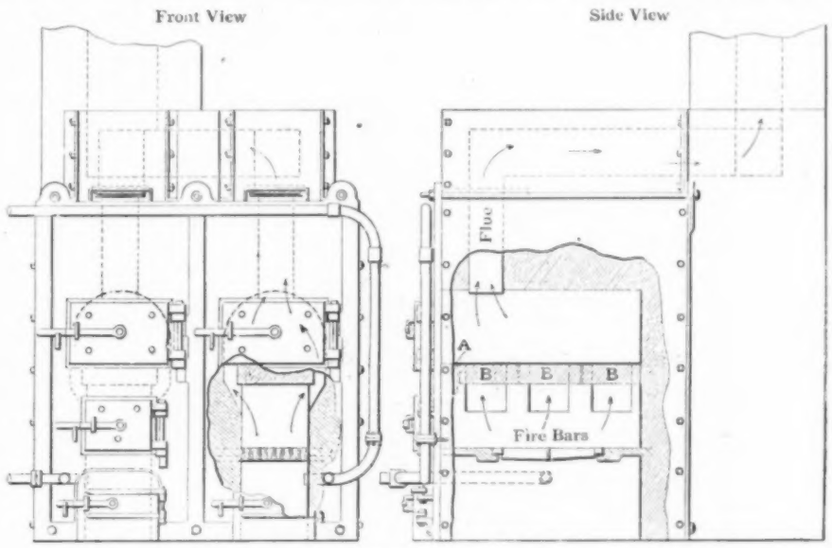


FIG. 1. HARDENING FURNACE FOR CUTTERS OF HIGH-SPEED STEEL

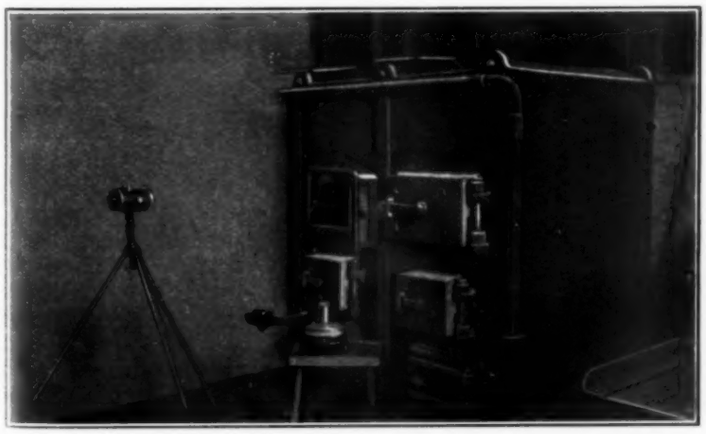


FIG. 2. HARDENING FURNACE AND PYROMETER

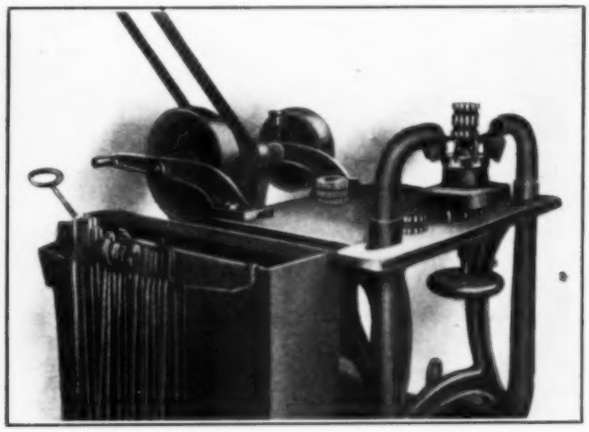


FIG. 3. AIR-COOLING TABLE

*Abstract of a paper presented to the Institution of Mechanical Engineers.

paratus and fittings depend very largely upon the use of formed milling cutters, and where the accuracy of the work so produced is directly dependent upon the accuracy with which the form of the cutter can be maintained for a prolonged period. It is desirable also that the cutters should have as long a life as possible in actual service not only to minimize the first cost and upkeep, but also to keep the output of the machines as continuous as possible, by reason of freedom from delays in changing the cutters. These points depend chiefly upon:

The quality of steel from which they are made.

The method of hardening adopted.

The care and accuracy with which the new cutters are made.

The facility and correctness with which the cutters can be ground up when they have become dull or lost their accuracy.

The Steel Used

There is, of course, nothing to compare with the recently developed high-speed steels as a material for cutters which are required to work at a high cutting speed and have the maximum possible life; and no difficulty is now experienced in obtaining work with a sufficiently satisfactory finish, provided care is exercised in the grinding and finish of the cutters, in the manner which will be described, and also if the cutting speeds and feeds are suitably arranged. Any of the best known makes of this class of steel can be used in conjunction with the system to be described.

The milling cutters are annealed, packed in spent powdered charcoal and steel turnings in cast-iron pans with covers which are luted down. These are placed in the annealing furnace first thing in a morning and are gradually heated up to 700 to 750 degrees Centigrade; this heat is usually reached by 1 o'clock and is maintained until about 5 o'clock, when the dampers are closed and the furnace is allowed to cool gradually for forty-eight hours. It is found that some makes of high-speed steel are satisfactorily annealed by the makers, but it is not the universal practice. Annealing in this manner is found to give thoroughly satisfactory results.

Method of Hardening

The furnace used for hardening cutters is shown in Figs. 1 and 2, and it has been found specially adapted for obtaining a soaking heat, together with the high temperature necessary in treating this class of steel and freedom from oxidation. The furnace is coke-fired and has a forced draft, and temperatures up to 2300 degrees Fahrenheit can be obtained.

In using the furnace the cutters are packed closely in powdered charcoal in sheet steel boxes about 6 by 6 by 3 inches. These boxes take from 2¾ to 3 hours to reach the necessary hardening temperature, the time taken varying with the weight of metal to be heated. The hardening temperature varies somewhat according to the class of steel being used, but may be said to be between 2000 and 2100 degrees Fahrenheit. The exact temperature necessary for satisfactorily hardening any particular class of steel is previously determined in the laboratory by exact experiments, and the temperatures obtained in the furnace are checked by means of a Fery radiation pyrometer, also shown in Fig. 2. This pyrometer is itself tested against a standardized Callendar pyrometer, and has so far been found to give extremely reliable results.

The cutters when sufficiently heated are quickly removed from the charcoal in which they have been packed, and are at once placed upon the hardening table shown in Fig. 3. This table is of a type frequently used in workshops for heating tools by gas, but when used for hardening cutters, air only is supplied through the two nozzles. These can be moved as required about vertical pivots so as to cause the air-blast to impinge upon the periphery of the cutters at any required points and simultaneously upon the vanes of the spindle upon which the cutter is placed, causing the whole arrangement to rotate and thus equalizing the cooling and hardening effect. The air delivered upon the cutter is drawn from an old culvert which passes under the floor of the workshop and through which a stream of water continually flows; hence at all times of the year a supply of cold damp air of maximum cooling effect is available. The temperatures used in hardening are such that the edges of the cutters are almost fused, and although different makes of steel have been found to vary somewhat in this respect, the general statement remains true of all of them. At the same time it is found that this fusing effect for a given heat is considerably minimized by the method of heating in closed boxes as compared with the ordinary method of heating tools, either in a muffle or in a direct gas flame, and even the scaling, which, with the latter systems is frequently very marked, is, with the method now described so slight that the cutters can be wholly freed from scale by placing momentarily under a revolving scratch brush.

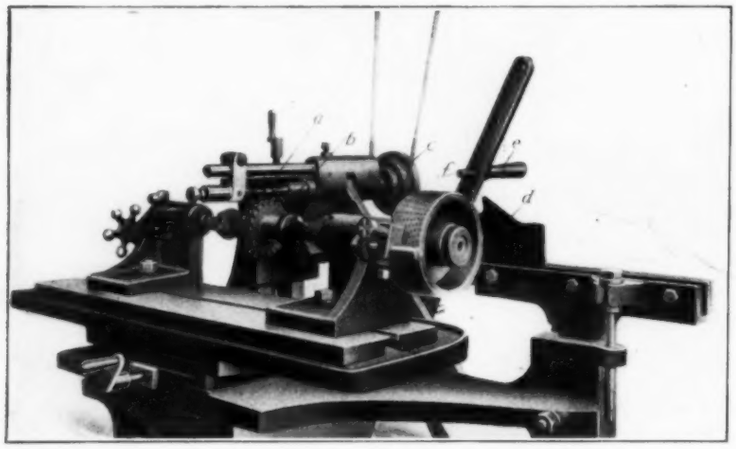


FIG. 4

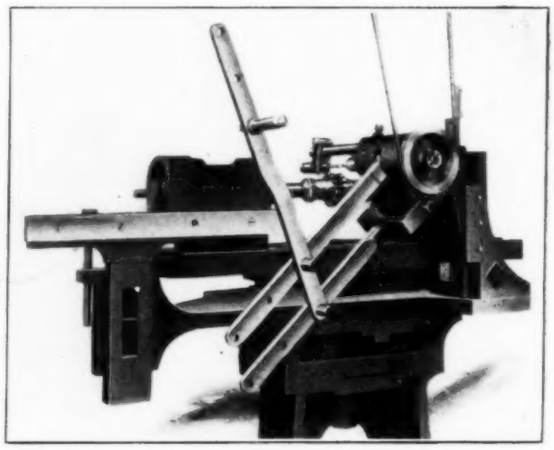


FIG. 5

MILLING FORMED CUTTERS OF HIGH-SPEED STEEL WITH A SPECIAL MACHINE

All difficulties as regards the expansion of the hole through the cutters in hardening are met initially, leaving the bore slightly smaller than is ultimately required—on the average about 0.01 inch less than the finished diameter; the expansion is usually about 0.003 to 0.005 inch, the average diameter of the mandrel being 1 inch. After hardening, the milling cutters are first chucked truly with the outside diameter in a self-centering chuck, and the internal bore is ground up truly to the finished diameter. After this the hardened cutters are chucked upon mandrels and the teeth are finished upon the special machines to be described.

Forming Cutter Teeth

Accuracy of form of the cutters is secured, both when being cut in the first place and also subsequently reformed, by turning the blanks and milling out the teeth in the ordinary manner, and then backing them off in the machine shown

in Figs. 4 to 7. In this machine the cutter to be formed is carried on a dividing head, so that one tooth at a time can be presented to the small milling cutter *a*, Fig. 4. This is mounted upon the cutter spindle *b* driven by a pulley *c*, from which catgut cord runs through an overhead gear, allowing the spindle to be moved within the necessary limits. The small cutter spindle-frame forms part of a system of adjustable pantograph links, so that its movement is an exact reproduction in miniature of the movement of the tracing pin upon the former *d* fixed in front of the machine. The operator, by means of the handle *e*, moves the pin *f* lightly along the former, and consequently also moves the cutter over the tops of the teeth to a similar but smaller shape. The small cutter is enlarged in diameter toward one end, so that it cuts away the back of each tooth upon the cutter to the necessary extent. Commonly a conical backing-off cutter is used, the angle of the cone being 20 degrees and the setting being such as to give an angle of relief of 10 degrees, that is, the axis of the cone is at right angles to the radial face of the tooth being backed off. It will be seen that this characteristic enables the machine to produce teeth of any form, upon a cutter backed off in every direction from the cutting edge, so that a clean cut can be taken with the sides as well as with the tops of the teeth.

In the case of those milling cutters in which grinding back the faces of the teeth so backed off might cause serious inaccuracy, owing to its throwing back the radial cutting edges of the teeth, the cutters are built up of annular sections which are either clutched together or clamped together upon plain faces, from which, after a particular grinding or series of grinding operations, the same amount is ground off as that by which the radial cutting edge has receded. Where the edges of the teeth are parallel or nearly parallel to the axis of the cutter, the profile is, of course, not appreciably affected by grinding back the faces of the teeth. A further means of avoiding such errors is also to be found in grinding the tops of the teeth in the manner subsequently described.

As it is found advantageous, in order to obtain a fine finish, to use helical teeth upon milling cutters, a fitting consisting of a sleeve with spiral slot, see Figs. 6 and 7, can be mounted on the same spindle as the milling cutter. A pin on a hinged arm centered above the backing-off cutter spindle is arranged to slide in the slot in this sleeve so that, as the frame carrying the copy and the cutter spindle is moved backward and forward along the axis of the cutter being backed off, the helical teeth are maintained in correct relation to the backing-off cutter; while at the same time they are backed off to the correct profile. Theoretically, of course, in such cases the axis of the cutter being operated upon could be inclined to the axis of the backing-off cutter spindle at an angle equal to that of the spiral of the cutter being produced, but in actual practice it is found that this adjustment is very seldom necessary, as the cone angle of the backing-off cutter, and also the amount of material which can be removed from the cutting edge of the cutter being produced, are both, comparatively speaking, small.

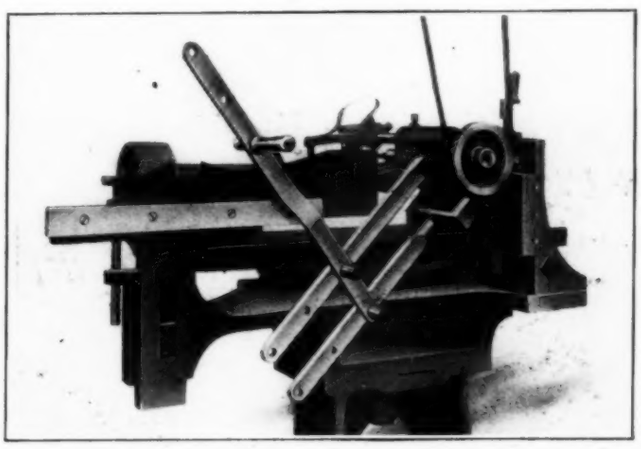


FIG. 6

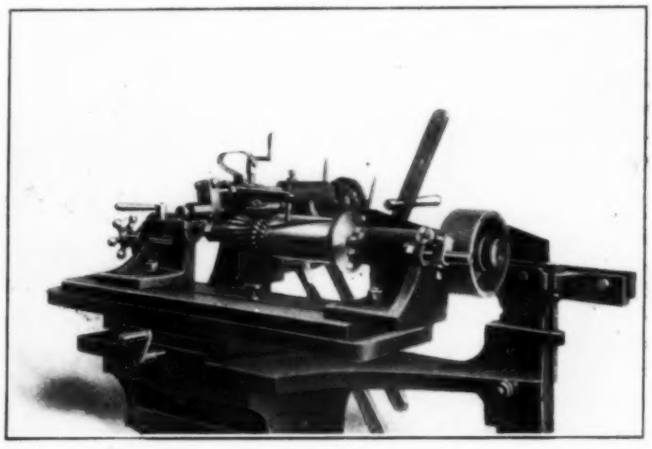


FIG. 7

MILLING FORMED CUTTERS WITH SPIRAL TEETH

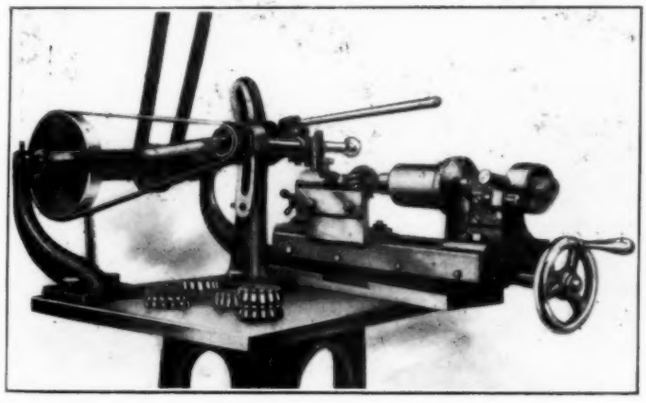


FIG. 8

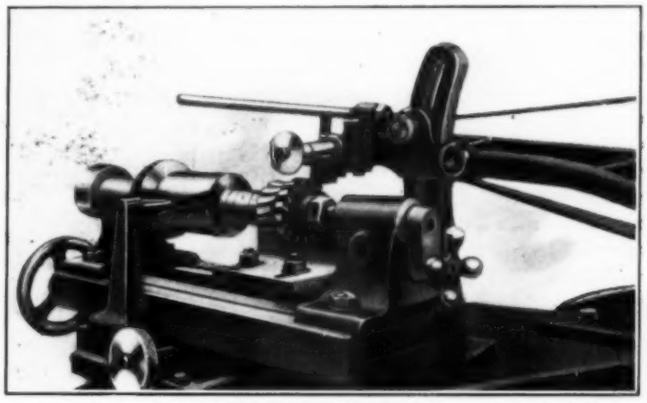


FIG. 9

GRINDING FORMED CUTTERS OF HIGH-SPEED STEEL

This machine has thus been found not only capable of backing off satisfactorily cutters of a shape which could not be backed off along the whole length of their profile in an ordinary relieving lathe in one operation, but it has been found possible to do the backing off in, approximately, one-third of the time required on a relieving lathe, while at the same time a less expensive class of labor may be employed, and the finish of the teeth is found to be better.

Grinding Cutters

Figs. 8 and 9 show the machine used

for sharpening the cutting edges of the hardened milling cutters and subsequently regrinding their faces or edges as required from time to time.

This machine has a grinding wheel mounted upon a spindle suspended on a swinging frame and follows the work by the use of a former, the profile of which is of the same magnitude as the one to be ground. In an ordinary way this former would not have the exact outline of the shape desired on the finished cutter, corrections having to be applied for the diameters of the tracing roller and also of the grinding wheel, the latter item being, of course, itself variable. This difficulty is overcome by using grinding wheels of special fast-cutting artificial stone which will perform a considerable amount of useful work before being appreciably reduced in diameter, and by making the diameter of the tracing roller equal to the diameter of the grinding wheel; there is in addition, of course, an adjustment for raising or lowering the former.

The milling cutter being ground is, as before, mounted upon a dividing head in the case of straight cutters, or upon a dividing head provided with helical sleeve in addition in the case of helical teeth cutters, and all the teeth are first ground along the tops to profile and afterward in the usual manner down their faces, the grinding wheel being, of course, set over to the angle of the spiral. The cutter thus finished has edges both of the maximum keenness and also of the maximum endurance due to correctly hardened high-speed steel, as only the thin skin partially oxidized in heating before hardening is removed.

Hitherto the apparatus employed upon sharpening profile cutters for milling machines in repetition work, such as is produced in small arms factories and elsewhere, has required the handling and attention of men with considerable training and skill, liable to error and consequently well paid to avoid it. The provision of simple machines such as those described now enables an unskilled man to regrind correctly all cutters brought to him with considerable rapidity and the minimum possibility of error. By standardization of the pitches of the teeth and their angles, and by the provision of suitable templets for each of the cutters commonly required, the use of these machines has been found to result in distinct economy, both in the upkeep of cutters and also in the quality of the work turned out.

Considerable advantages result from being able to reform accurately the contour of the teeth in addition to grinding the face. In ordinary use the teeth of milling cutters are damaged not only on the face, but to an even greater extent on the top, and it has frequently been found that removing, say 0.002 inch from the top has as beneficial an effect as removing 0.005 inch from the face, and with this additional advantage that, when a tooth has been ground to its fullest extent from the face, it can be further sharpened on the top while still retaining its correct figure, until the tooth is too short through not allowing the necessary clearance; and this consideration will in many cases lengthen the life of a cutter by 10 per cent.

The life of some milling cutters prepared by the methods indicated above has been extraordinary; for example, a cutter working in a self-acting cross-milling machine and operating upon the bodies of the service rifle at an average cutting speed of 69 feet per minute, with a feed of 1¾ inches per minute and a depth of 0.08 inch, and taking a cut of an average width of 1 11/16 inch and ⅞ inch long, has produced, at the time of writing, 39,170 bodies and is still good for about half as many more. This particular cutter has been reground across its face twenty-five times. The composition of the steel upon which it operates is 0.5 to 0.6 carbon with an ultimate tensile strength of not less than 35 tons per square inch.

Electrical development in Peru is likely to call for increased purchases of material, notwithstanding the fairly large installations that have been made during the last two years. Hydraulic and electrical engineers the world over are familiar with the power that the Andes waters hold in reserve, but not all of them have kept pace with the recent application of this power and with the prospects for its further utilization. Some of the grander projects will have to wait a further period of industrial growth before they can become commercially feasible.

Drop Forging on the Pacific Coast

By Holden A. Evans*

The Pacific coast offers a good field for a well equipped die-sinking and drop-forging establishment. At the present time the only plant of this kind is in the construction department at the Mare Island navy yard. In this department there is sufficient work to keep four die sinkers and one drop forger constantly employed. Their work has greatly reduced the manufacturing costs of forgings. The die and forge shops were put in operation about three years ago. The die room is located in the machine shop and the forge room in an annex to the blacksmith shop.

In the die room there are two die-sinking machines, two lathes, two shapers, a drill press, a die-slotting machine, a surface grinder and the usual small tools and work benches. A heavy horizontal milling machine is to be added to the equipment. The planer work is done in the machine shop adjacent. The half-tone illustration, Fig. 1, shows the arrangement of the tools in the die room. In the drop-forge room there are: One 1200-pound hammer, one 2400-pound hammer, two trimming presses, one forging furnace and one furnace for tempering dies.

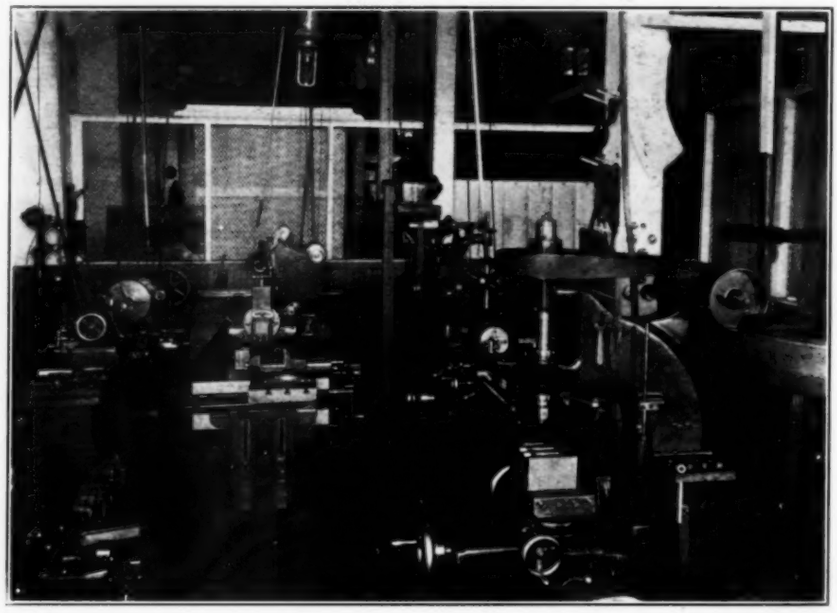


FIG. 1. PORTION OF DIE SINKING SHOP, MARE ISLAND NAVY YARD

By standardizing ship fittings and manufacturing them in quantities for stock to be used as needed, the cost of this class of work has been greatly reduced. Before the establishment of the drop-forge plant all such fittings were made as needed, a few at a time, by hand in the

*Naval constructor, Mare Island navy yard.

blacksmith shop. The cost was necessarily high; especially so as wages on the Pacific coast are high. By standardizing such fittings and manufacturing in quantities not only is the cost materially reduced, but also the delay of waiting is eliminated. In the case of urgent repairs to ships delay in any part of the work is of great importance. The half-tone illustration, Fig. 2, shows the general classes of fittings that are drop forged.

High-class die steel is not used as it is found that for the kinds of fittings manufactured the lower-priced material answers equally as well. There is not only much less cost of material, but also of labor, owing to greater ease of working the softer material. The die material is purchased in open-hearth billets 10 feet long of the proper sizes and is cut to the required lengths for dies. For dies that will receive hard wear steel of 0.60 per cent. carbon is used. For the general run of dies steel of 0.40 per cent. carbon is used. These classes of material cost, delivered at Mare Island, about 3 cents per pound. This is less than half the cost of high-grade die-block steel. It is, of course, necessary to use cyanide in tempering these dies. The character of the dies used is shown in the half-tone illustration, Fig. 3.

Dies for very accurate work are made from high-grade steel for the reason that this material stands up better under the hammer than does the open-hearth steel of 0.40 to 0.60 carbon content. For ordinary fittings as shown in the illustration slight sinking of the impression makes practically no difference; the fittings are of such a type that absolutely accurate dimensions (within a few thousandths of an inch) are not required.

Careful observations were made of the dies after a thousand or more forgings had been made and it was found that some of the impressions had sunk a maximum of 0.004 of an inch; but the majority showed no depression.

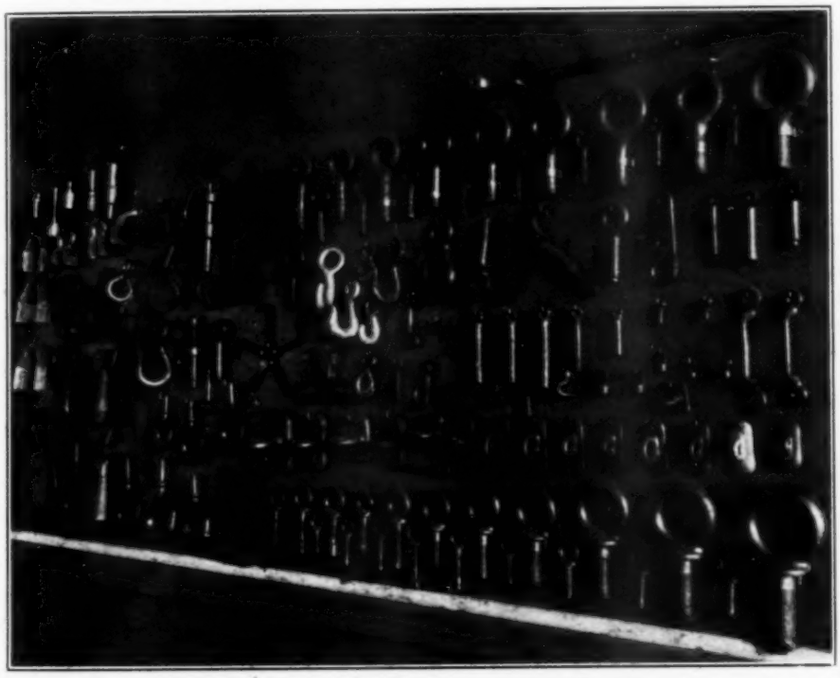


FIG. 2. DROP-FORGED SHIP FITTINGS

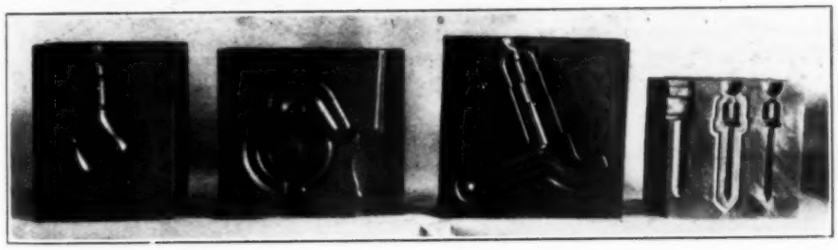


FIG. 3. SPECIMEN DROP-FORGE DIES FOR SHIP FITTINGS

Usually after rubber matting has been in use for a time its uniform gray disappears, the oil and grease collecting upon it from boots and by dripping tending to rot and discolor it. To prevent the destruction and discoloration the matting should be painted with lead-colored paint which, when dry, gives a varnished surface. Not only is this oilproof, but it gives a bright look to the matting and renders it easily cleaned.—*Horseless Age.*

Need of Care in Using Cyanide

By S. A. Nyde

Cyanide of potassium is in common use for hardening purposes in shops all over the country. All who use it probably know, in a general way, something of its poisonous nature; few, I think, really appreciate all of its dangerous qualities.

For 18 years I have been identified with a large plant where over half a ton of cyanide of potassium is used each year and during that time have seen some very bad accidents due to carelessness in handling the stuff. "Familiarity breeds contempt." Those who use it constantly get careless or indifferent to the danger—till they get caught.

Some time ago a professor of chemistry accidentally tasted of a solution of cyanide of potassium during a lecture before his class; though but a few drops passed his lips, he nearly died right where he stood.

I wish to call attention to the fact that the water into which pieces of work that are heated in cyanide are dipped, becomes in a short time nothing less than a solution of cyanide of potassium, and is just as dangerous to life as the stuff the professor tasted.

I have also seen men get terribly burned because of carelessness in handling cyanide, as the least bit of moisture on the piece to be hardened, on the frame or wire cage into which small pieces are put, or on the hook by which the frame is suspended, causes the molten cyanide to sputter and fly like red-hot bullets; and it is nearly as dangerous, destroying the sight if it gets in the eye.

I wish to caution cyanide hardeners against wearing low shoes or neglecting to button or lace high shoes. One of the worst burns I ever saw was due to just this carelessness. A little dampness on the piece being put into the pot caused a bad sputtering of the cyanide, a large spatter of which dropped into the open front of the hardener's unlaced shoe, burning his entire instep clear to the bone in a most horrible manner. The subsequent inflammation caused by the poison in the wound nearly resulted in the loss of his foot.

There is another kind of burn that is as painful, if not as dangerous; that is, a "dry burn." One day a workman dropped a hammer into an old hardening pot which had been emptied some time before. Thrusting his bare arm into the narrow pot to get the hammer, he scraped off some skin; cyanide got into the place and in a few days he had a very ugly looking running sore which spread till it covered a space 1 inch wide and 4 inches long, causing him weeks of intense suffering.

The best remedy for cyanide burns that I know of is equal parts of linseed oil and lime water.

A Gage for Use in Producing Accurate Tapers*

Measuring Tapers or Establishing Their Proportions by a Gage with Adjustable Jaws Set by a Pair of Disks

BY C. C. STUTZ

It has been customary, and I have no doubt it is so at present to a great extent in machine-tool shops, to produce a set of standard tapers to be used in connection with their line of manufacture. These standard taper gages are carefully kept in the company's safe, and are used for reference only. Another set of gages, an exact copy of the first set, is then made for shop use, and this second set is occasionally compared with the first. This method has always appeared to me very cumbersome, and to overcome it the tool illustrated in Fig. 1 was designed and made some years ago.

It is very evident that if two round disks of unequal diameter are placed on a surface plate a certain distance apart, two straight-edges touching these two disks will represent a certain taper. It is also evident that with the measuring instruments now in use it is a very simple matter to accurately measure the diameters of the two disks, and also to accurately measure the distance these disks are apart. It will readily be seen that these three dimensions accurately and positively determine the taper represented by the straight-edges touching the rolls. If now a proper record is made of these three dimensions it is very evident that these conditions can be reproduced, and this is in short the idea which underlies the use of the tool herewith illustrated.

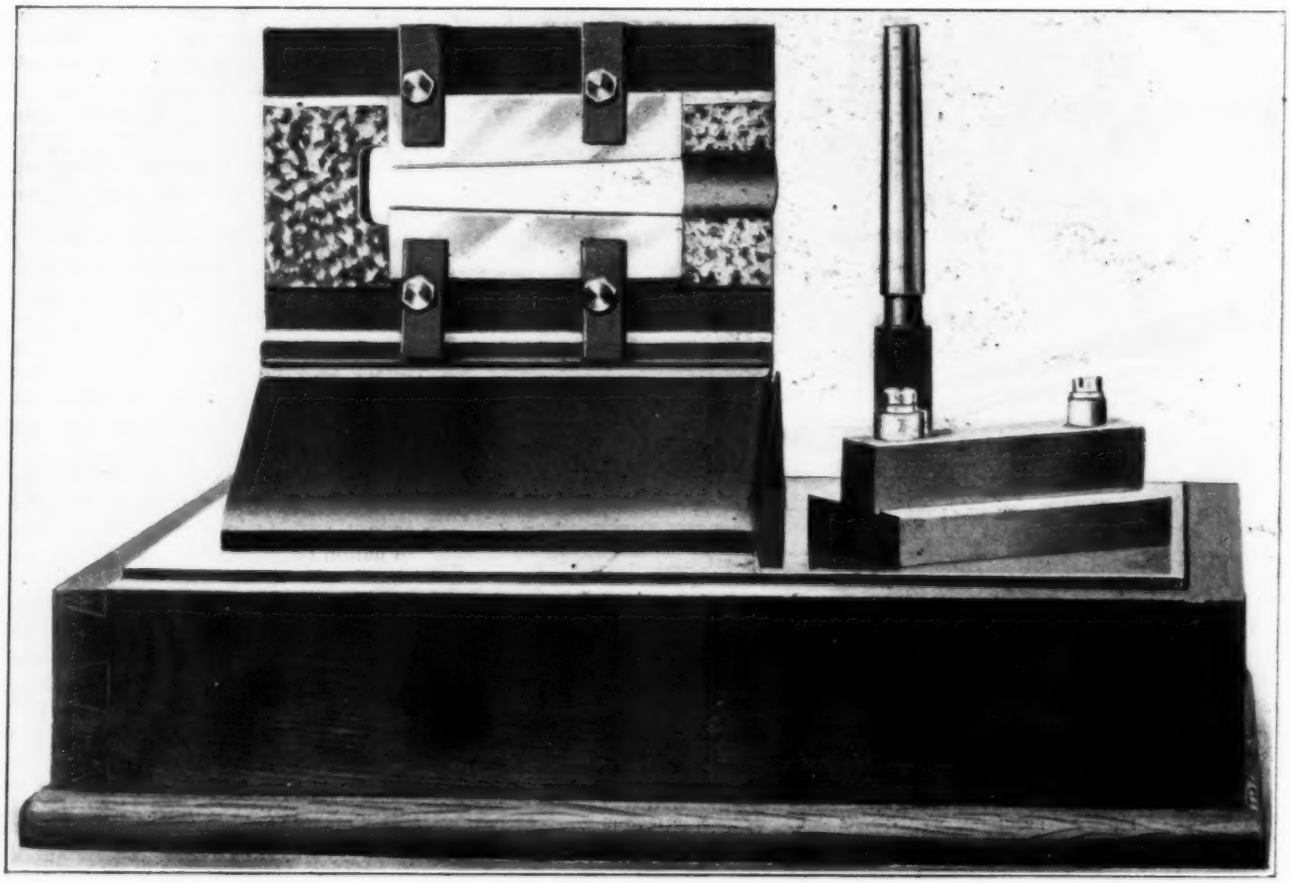


FIG. 1. TAPER GAGE WITH ADJUSTABLE JAWS AND SETTING DISKS

Some years ago I had occasion to make a special taper plug which was sent to one of the manufacturers of arms in Russia. On the plug being received the management of the factory requested that a female gage to fit the plug be forwarded. On the plan of the tool illustrated the plug was reproduced from the dimensions noted at the time. A second plug was made, the female gage was produced and shipped. On the female gage being received, it fitted perfectly with the plug previously shipped, illustrating the case with which tapers could be reproduced by means of the tool described.

The following formulas may be of service in connection with a gage of this character:

To Find Center Distance Between Disks

Suppose we have two disks as shown in Fig. 2, whose diameters are respectively 1¼ and 1 inch. We wish to construct a taper of ¾ to the foot and must determine the center distance l between disks in order that the gage jaws when touching both disks shall give that taper.

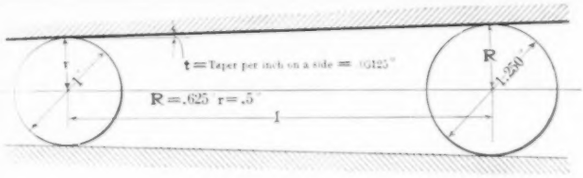
Let R = radius of large disk, or 0.625 inch.
r = radius of small disk, or 0.500 inch.
t = taper per inch on side, or

$$\frac{0.750}{24} = 0.03125 \text{ inch.}$$

Then

$$l = \frac{R - r}{t}\sqrt{1 + t^2} =$$

*Copyrighted, 1908, by Hill Publishing Company.



Taper per foot = ¼"

FIG. 2

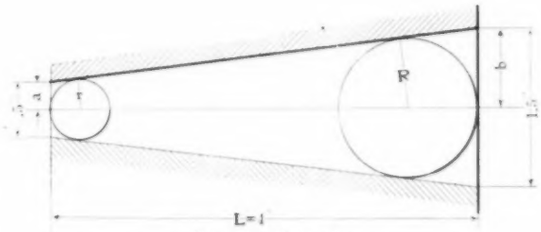


FIG. 3

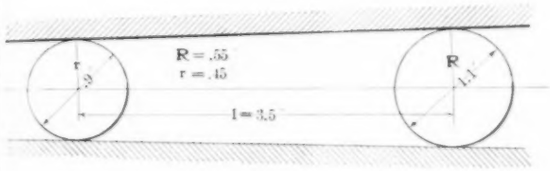


FIG. 4

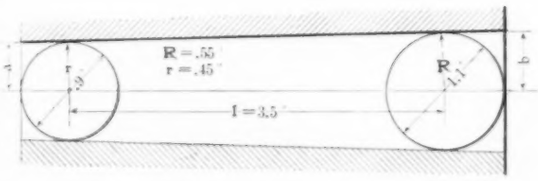


FIG. 5

To find Center Distance (l), refer to Fig. 2.

$$l = \frac{R - r}{t} \sqrt{1 + t^2}$$

To find Disk Diameters, refer to Fig. 3.

$$r = \frac{a}{L}\left[\sqrt{L^2 + (b-a)^2} + (b-a)\right]$$

Dia. Small Disk = $2r$

$$R = \frac{b}{L}\left[\sqrt{L^2 + (b-a)^2} - (b-a)\right]$$

Dia. Large Disk = $2R$

To find Taper Per Foot (T), refer to Fig. 4.

$$T = 24\left(\frac{R - r}{\sqrt{l^2 - (R-r)^2}}\right)$$

To find Width of Opening at Ends, refer to Fig. 5.

$$a = r\left[\frac{l}{\sqrt{l^2 - (R-r)^2}} - \sqrt{\left(\frac{l}{\sqrt{l^2 - (R-r)^2}}\right)^2 - 1}\right]$$

Width of Opening at Small End = $2a$.

$$b = R\left[\frac{l}{\sqrt{l^2 - (R-r)^2}} + \sqrt{\left(\frac{l}{\sqrt{l^2 - (R-r)^2}}\right)^2 - 1}\right]$$

Width of opening at Large End = $2b$.

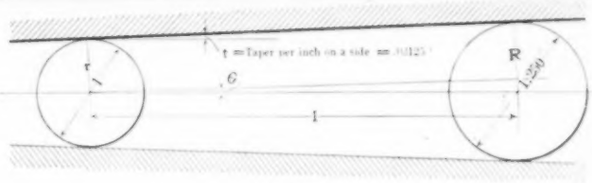


FIG. 6

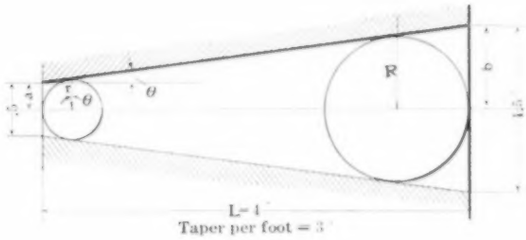


FIG. 7

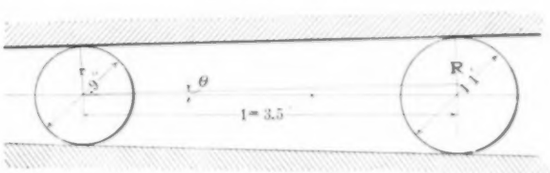


FIG. 8

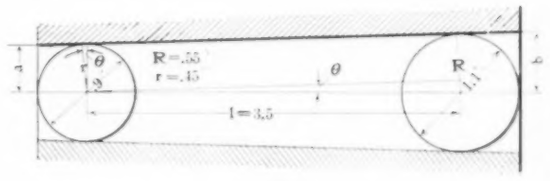


FIG. 9

To find Center Distance (l), refer to Fig. 6.

$l = \frac{R - r}{Sin\ \theta}$, in which θ = the angle whose tangent is the taper per inch on a side, or t.

To find Disk Diameters, refer to Fig. 7.

$$r = \frac{a}{Cos\ \theta}(1 + Sin\ \theta),\quad R = \frac{b}{Cos\ \theta}(1 - Sin\ \theta),$$

in which θ = the angle whose tangent = $\frac{\frac{b-a}{2}}{L}$

Dia. Small Disk = $2r$.
Dia. Large Disk = $2R$.

To find Taper Per Foot (T), refer to Fig. 8.

$T = 24\ (tan\ \theta)$, in which θ = the angle whose sine = $\frac{R - r}{l}$.

To find Width of Opening at Ends, refer to Fig. 9.

$$a = r\ tan\left(45° - \frac{\theta}{2}\right),\quad b = R\ tan\left(45° + \frac{\theta}{2}\right),$$

in which θ = the angle whose sine = $\frac{R - r}{l}$.

Opening at Small End = $2a$.
Opening at Large End = $2b$.

FORMULAS FOR USE IN CONNECTION WITH TAPER GAGE.

$$\frac{0.125}{0.03123}\sqrt{1.000976} = 4 \times 1.0005 = 4.002$$ inches.

To Find Disk Diameters

Suppose the gage jaws are to be set as in Fig. 3 for a three-inch per foot taper whose length is to be four inches. The small end is to be exactly ½ inch and the large end for this taper will, therefore, be 1½ inches. What diameter must the disks be made so that when the jaws are in contact with them and the distance L over the disks measures 4 inches, the taper will be exactly three inches per foot? Here a represents ½ the width of opening at the small end, and b one half the width of opening at the large end. The radius of the small disk may be found by the formula:

$$r = \frac{a}{L}\left\{\sqrt{L^2 + (b-a)^2} + (b+a)\right\}.$$

Then

$$r = \frac{0.25}{4}\left(\sqrt{16 + 0.25} + 0.5\right)$$
$$= 0.0625\,(4.0311 + 0.5) = 0.2832.$$

Diameter small disk = 0.2832 inch × 2 = 0.5664 inch.

For the large disk:

$$R = \frac{b}{L}\left\{\sqrt{L^2 + (b-a)^2} - (b-a)\right\}.$$

Then

$$R = \frac{0.75}{4}\left(\sqrt{16 + 0.25} - 0.5\right)$$
$$= 0.1875\,(4.0311 - 0.5) = 0.6621.$$

Diameter large disk = 0.6621 inch × 2 = 1.3242 inches.

To Find Taper Per Foot

In duplicating a taper the gage jaws may be set to the model and by placing between the jaws a pair of disks whose diameters are known the taper per foot may be readily found. For example, the jaws in Fig. 4 are set to a certain model, two disks 0.9 and 1.1 inch diameter are placed between them and the distance over the disks measured, from which dimensions l (which is 3.5 inches) is readily found by subtracting half the diameters of the disks. Here l represents the center distance as in Fig. 2. To determine the taper per foot which may be represented by T, the formula is:

$$T = 24\left(\frac{R-r}{\sqrt{l^2 - (R-r)^2}}\right).$$

Then

$$T = 24\left(\frac{0.1}{\sqrt{12.25 - 0.01}}\right) = 24\left(\frac{0.1}{3.4985}\right)$$
$$= 0.684$$

Taper per foot = 0.684 inch.

To Find Width of Opening at Ends

If, with the ends of the gage jaws flush with a line tangent to the disk peripheries as in Fig. 5, we wish to find the width of the opening at the small end where a represents one-half that width, the following formula may be of service, the disks being as in the last example 0.9 and 1.1 inch diameter respectively, and the center distance 3.5 inches:

$$a = r\left\{\frac{l}{\sqrt{l^2 - (R-r)^2}} - \sqrt{\left(\frac{l}{\sqrt{l^2 - (R-r)^2}}\right)^2 - 1}\right\}$$

Then

$$a = 0.45\left\{\frac{3.5}{\sqrt{12.24}} - \sqrt{\left(\frac{3.5}{\sqrt{12.24}}\right)^2 - 1}\right\}$$

$$= 0.45\left(1.00043 - \sqrt{0.00086}\right) = 0.45\,(1.00043 - 0.0293) = 0.437.$$

0.437 inch × 2 = 0.874 inch width of opening at small end of gage.

Similarly the width of opening at the large end of the gage may be found as follows where b = half the width at large end.

$$b = R\left\{\frac{l}{\sqrt{l^2 - (R-r)^2}} + \sqrt{\left(\frac{l}{\sqrt{l^2 - (R-r)^2}}\right)^2 - 1}\right\}$$

Then

$$b = 0.55\left\{\frac{3.5}{\sqrt{12.24}} + \sqrt{\left(\frac{3.5}{\sqrt{12.24}}\right)^2 - 1}\right\}$$

$$= 0.55\left(1.00043 + \sqrt{0.00086}\right) = 0.55\,(1.00043 + 0.0293) = 0.5663.$$

0.5663 inch × 2 = 1.1326 inches = width of gage opening at large end.

The formulas for r and R appear a little complicated; actually, however, they are simple enough. The expression

$$\frac{l}{\sqrt{l^2 - (R-r)^2}}$$

which appears twice in each formula is readily given its numerical value and upon this substitution the appearance is generally simplified.

Finding Center Distance by Trigonometry

Some may prefer to solve the foregoing problems by trigonometry. The diagram Fig. 6 duplicates the conditions in Fig. 2, and it is obvious that t, the taper per inch on each side (0.03125″) = $\tan.\ \theta$, which angle we find to be 1° 47′ 20″. To find center distance l the following formula may be used:

$$l = \frac{R-r}{\sin.\ \theta}.$$

Then

$$l = \frac{0.625 - 0.5}{\sin.\ 1°\ 47'\ 20''} = \frac{0.125}{0.03123} = 4.002$$ inches.

Disk Diameters

In Fig. 7 the conditions of the problem Fig. 3 are reproduced, only here r and R are to be found by trigonometry in determining the diameters of the two disks. Angle θ is readily found as the tangent of this angle is obviously equal to

$$\frac{1.5 - 0.5}{\frac{2}{4}} = 0.125 = \tan.\ 7°\ 8'.$$

To find r use the formula

$$r = \frac{a}{\cos.\ \theta}\ (1 + \sin.\ \theta)$$

Then

$$r = \frac{0.25}{0.99226}\ (1 + 0.12418) = 0.2519$$
$$\times\ 1.12418 = 0.2832.$$

Diameter small disk = 0.2832 inch × 2 = 0.5664 inch.

Similarly,

$$R = \frac{b}{\cos.\ \theta}\ (1 - \sin.\ \theta)$$

Then

$$R = \frac{0.75}{0.99226}\ (1 - 0.12418)$$
$$= 0.7549 \times 0.87582 = 0.6621.$$

Diameter small disk = 0.2832 inch × 2 = 1.3242 inches.

Taper per Foot

In Fig. 8 we have the problem reproduced from Fig. 4, of finding the taper per foot when the disk diameters and their distance apart are known. To solve this by trigonometry we may consider angle θ as representing the slope on one side of the taper, hence the total taper per foot or T may be expressed as T = 24 ($\tan.\ \theta$). We can readily find this angle as follows:

$$\sin.\ \theta = \frac{R-r}{l} = \frac{0.55 - 0.45}{3.5}$$
$$= \frac{0.10}{3.5} = 0.0285 = \sin.\ 1°\ 38'.$$

Then $T = 24\ (\tan.\ \theta\ ) = 24\ (\tan.\ 1°\ 38')$ = 24 (0.02851) = 0.6842.

Taper per foot = 0.6842 inch.

Width of Opening

Considering now the case in Fig. 9, where, as in Fig. 5, it is desired to find the width of opening in the gage at a point tangential to the extremities of the disks, we may solve a by the formula

$$a = r \tan. \left(45° - \frac{\theta}{2}\right).$$

From the data of the problem we easily find the angle θ; for $\sin. \theta = \frac{R - r}{3.5}$ $= 0.0285 = \sin. 1° 38'$ as in the preceding problems.

Applying formula, $a = r \tan. \left(45° - \frac{\theta}{2}\right)$ we have

$a = 0.45$ (tan. 44° 11′) $= 0.45$ (0.97189) $= 0.437$.

0.437 inch $\times$ 2 $=$ 0.874 inch width of opening at small end of gage.

To find dimension b, Fig. 9, by trigonometry we use the formula

$$b = R \tan. \left(45° + \frac{\theta}{2}\right)$$

$= 0.55$ (tan. 45° 49′) $= 0.55$ (1.02892) $= 0.566$.

0.566 inch $\times$ 2 $=$ 1.132 inches width of gage opening at large end.

A Slotting Attachment for Small Holes

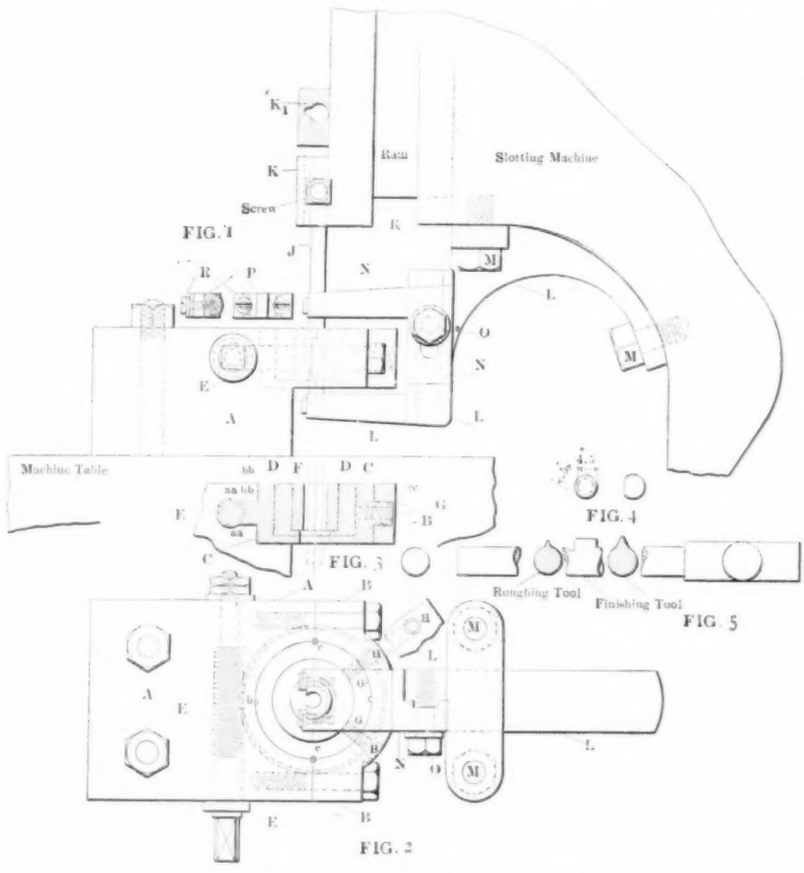
By George Bilham

The accompanying sketches illustrate an arrangement for slotting small D-shaped holes in the article shown at Fig. 4, which is of such a length in proportion to the diameter that a tool of the common type and of sufficient strength to take a parallel cut of reasonable depth cannot be used, thus necessitating the taking of many fine cuts and the consequent production of almost infinitesimal shavings in large quantities, and even then leaving the hole slightly tapered and requiring further adjustment with file and scraper to insure a good fit. Then too, the material is of such a nature that it cannot be broached in the ordinary way, it being a steel which drags on the application of a cut of any width such as is taken by a broach.

As these articles are constantly in course of manufacture the attachment shown has been designed to bring the time for performing the operation of slotting these holes to within reasonable limits and seeing that an average saving of 33 per cent. is expected, and as there are several articles in course of manufacture which have a similar hole, the outlay necessary would appear to be justified.

The sketches show the gear attached to the machine; Fig. 1 is an elevation with the necessary parts of the machine; Fig. 2, a plan less the parts of machine and tool; Fig. 3, a section through the bracket A with worm and worm-wheel; Fig. 4, an end view of the hole to be slotted, and Fig. 5, the tool with enlarged sections.

The part carrying the work and attached to the table consists of the bracket A with cap B, the worm-wheel C which also acts as the chuck for holding the work, the split bush D (in two parts of which several are necessary to accommodate the varying outside diameters of the various pieces to be slotted) and the worm E which actuates the worm-wheel C and is provided with a square to suit the handle on the machine it is proposed to use. The work F is secured in the worm-wheel chuck C by the two slotted screws $G\,G$ access to which is obtained through the cap B at $H\,H$. The worm-wheel is made a good fit in the bracket between the faces $a\,a$ and is lubricated at the top face by the grooves $b\,b$ and the bottom face by the holes through the wheel at $c\,c$, which should be brought into line as shown in plan with the grooves in the bracket A.



SLOTTING ATTACHMENT FOR SMALL HOLES

In Fig. 1 is shown the tool J in position with the tool-bar K attached to the ram of the machine, the front part of the tool-bar is of the section shown at $K\,1$, the groove cut at front of large hole allowing the tool to be changed while the bar is bolted to the ram. Two tools are necessary for each size of hole, one for roughing and one for finishing similar in shape to section in Fig. 5, though by the time the first roughing tool is worn out the first finishing tool will be worn down sufficiently to allow of it entering the hole before slotting so that when renewing tools it will be necessary to make only finishing tools.

The bracket L secured in the throat of the machine by the screws M, is carried forward under the bracket A to form the bottom guide for the tool J, the top guide N is adjustable on and secured to L by the screw O, so that it can be raised to provide for any piece of work longer than F, as the length varies from 0.75 to 1.75 inches in length. The guides are provided with the bushes $P\,P$ secured by the screws $R\,R$, and which can easily be changed to suit the various sizes of the tools.

It is advisable to have a leather washer on the tool between the bottom of the work and the guide to prevent the chips scoring the tool or guide bush.

This attachment, it will readily be seen, provides for a continuous circular motion for the work and at the same time a guide for the tool, the ordinary slides of the machine providing for movements in other directions.

No one can have followed agricultural-machine manufacture in Germany for the past 10 years and doubt that improvement has been steady and substantial, and that the German manufacturer proposes, as early as possible, to supply the home trade in all its branches and to have his share in the trade of other countries. From now on it will be more and more a question of the best possible product.

Cat Head for Connecting-rod Ends

By L. E. Salmon

The style of cat head illustrated in Fig. 1 is used almost exclusively on connecting-rods for cutting out the large holes in solid end rods in which the brass bushings are forced, such a rod being shown in Fig. 3. *A* is the hole in the rod; *B* is the piece removed, which very often comes in handy on other jobs, such as the making of bushings, expansion arbors, etc.

Although the general design of the head can be readily seen from the drawing, a few words of description will not be out of place. The body of the tool is a mild-steel forging finished all over by being first strapped on the face plate of a lathe, a 2-inch hole bored through the center, and one side faced up and finished on an arbor; then a 1½-inch hole is drilled in one end of each of the rectangular holes for a start for the slotter, where it goes next to have the holes slotted, the outsides trimmed and the hole splined for the key. It is then drilled, counterbored and tapped for the set-screws, as shown, these set-screws being made of tool steel and tempered. The shank is next made, splined and fitted to drive lightly, being held securely in place by the two keys and two set-screws, as shown, thus making a most rigid and efficient tool.

The pilot or guide *D* is in this case a rose reamer, or, as commonly called in a locomotive shop, a bur reamer; it is probably so called because some of the old styles have a bur on the end of the hole when they go through.

The object of making the pilot in this way was to have it cut its own size as it went through, which insured a fit on every hole without taking any special care when the hole was first drilled. As the end of the reamer is anywhere from 1½ to 2 inches in advance of the tools, it has a good firm bearing by the time that the tools begin to cut. As will be noticed, it is screwed into the shank with a right-hand thread; this makes it easy to remove it to be ground or replaced in case of breaking, etc.

The slots marked "inside tool only" and "outside tool only" are made with the back or inside face at an angle with the center line; this is done to give these two tools the necessary clearance from the sides of the cut without weakening them by grinding the clearance. This is also a great time saver when it is considered that the tools require grinding only on the top face and nose, being left in every other respect as they come from the smith shop.

These tools, including the center tool, are simply pieces 8 inches long cut off a bar of ¾x1½-inch high-speed steel and tempered. The little shaping required is done on a universal tool grinder, which takes but a few minutes; they are thus set to the approximate size by use of shims of various thicknesses, as shown in Fig. 2. As the hole is reamed afterward, the side does not need to be accurate, although from 1/32 to 1/16 inch is usually left for reaming.

Fig. 2 gives a rough idea of the shapes of the tools, and a cross-section of the cut made by the tools is also shown below the shims.

These cat heads are used in pairs on a two-spindle drill, as in cutting out the holes in the parallel rods, both ends being done at once in the following manner: The rods are first planed, milled, paneled and laid out; they then go to the driller, who sets the two heads of his machine the required distance apart and uses two drills 1 15/16 inch in diameter, with which the hole *E*, Fig. 3, is drilled in each end. After drilling all the rods of the same size, he sets his cat head to size by measuring from the outside of the tools to the opposite side of the guide. In this case it is the rose bit *D*, Fig. 1, and he deducts 1 inch or half its diameter. These heads are then put in the two spindles and forced up hard by means of a key that fits in the slot in the shank, and through a corresponding slot in the spindle head. This key has a ⅛-inch draw; an additional key is used, as shown at *G*, for the drive. After the three tools begin to cut, he measures the outside of the cut to be sure that it is the required size. Having satisfied himself on this point, he puts the feed on again and it becomes simply a matter of changing rods as fast as they are cut out.

These tools require so little attention after they are once set that the operator can devote almost his entire time to drilling, cat-heading, or tapping the oil cups on another drill press placed alongside of his two-spindle machine. When the rods have all had the hole cut, they are reamed.

I regret that I have no record giving time, cost, etc., of these tools and their work, but I feel confident that the mechanic who reads this will very readily see the usefulness, strength and efficiency of this kind of a tool.

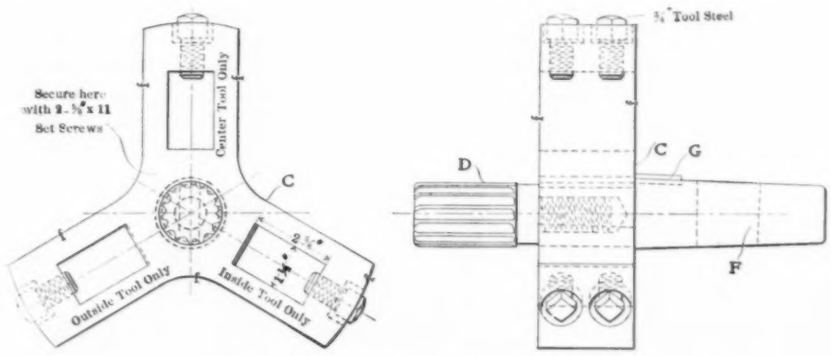


FIG. 1. CAT HEAD FOR CONNECTING ROD

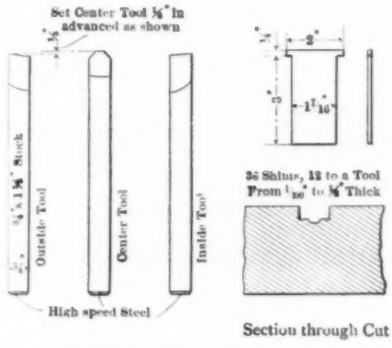


FIG. 2. TOOLS, SHIMS AND SECTION OF CUT

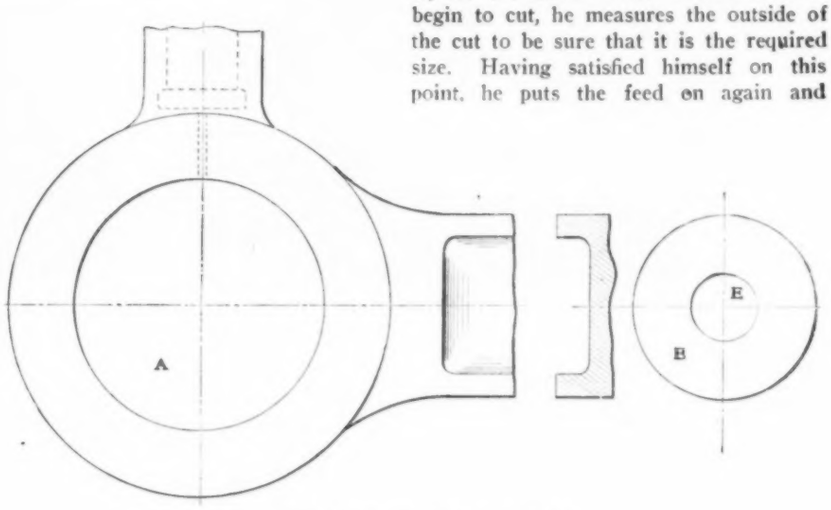


FIG. 3. ROD END AND BLANK REMOVED

Foremanship

By C. A. Marston

The foreman of a machine shop is the man who is held directly responsible for the work, the workmen, and everything connected with the running and maintenance of his department. In order for him to obtain the responsible position that he holds, he must have the necessary qualifications and be able to get out the work satisfactorily.

To be a success he must get the confidence of the men; must let them feel that he is back of them, and will stand by them in times of trouble; must not become intimate with any particular ones, but be friendly and agreeable with all; must not tell what he did in this or that shop when everyone else failed, but convince his men without unnecessary bragging that he knows his business, that he is there to show them how to get around a difficult piece of work if occasion demands.

Above all things, he must not rush a man when he is not in a hurry for the job.

I knew the foreman of a small shop with about 75 men, who was in a rush for every job he would give out; when completed they would lie on the floor for a week or so, untouched. He soon lost the confidence of the men, and when he really did want a job in a hurry he never could get it. A workman does not very often deliberately kill time on a job, but carries it along to completion anxious to get it off his hands. The successful foreman who has the confidence and good will of his men will need only to say that he would like a job as soon as he can get it. The result will be that he will get it as fast as the man can possibly turn it out.

A cool-headed, peaceful and diplomatic man is the man who makes good; he doesn't run around the shop like mad, grumble at everyone, and get dissatisfied with the work or the way it is done. Instead he has a pleasant nod for all; at the same time though he knows how to tell a man in a few forceful words, which do more good than all the "cussing" he could give in five minutes, what to do and how to do it.

Grinding Milling Saws

By Ethan Viall

It has often been a source of wonder to me why some factories grind their milling saws in the way they do. Glance at the side of almost any saw put out by a cutter factory and you will see crescent-shaped radial lines running from the hole to the teeth, showing at once how the saw was ground on the sides after hardening. Fig. 1 illustrates the general way this is done. The cut shows a cylinder wheel, though a cup or saucer wheel is as often used. Sometimes the saw jig is set above or below the center of spindle—the practice varies in different shops—while some insist that the centers must be at the same hight.

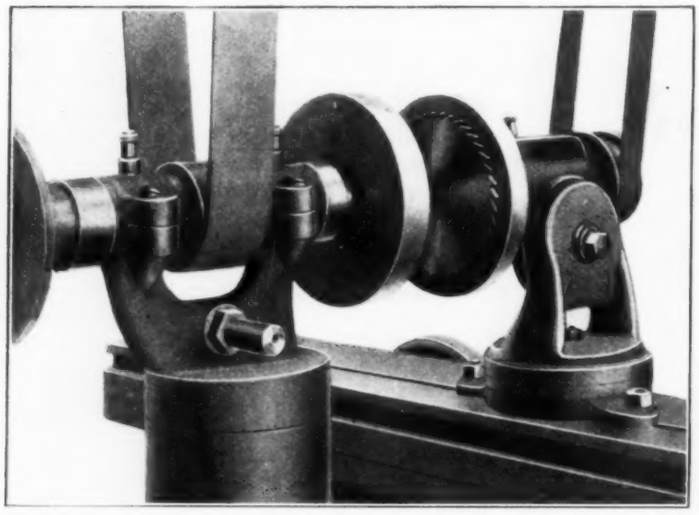


FIG. 1

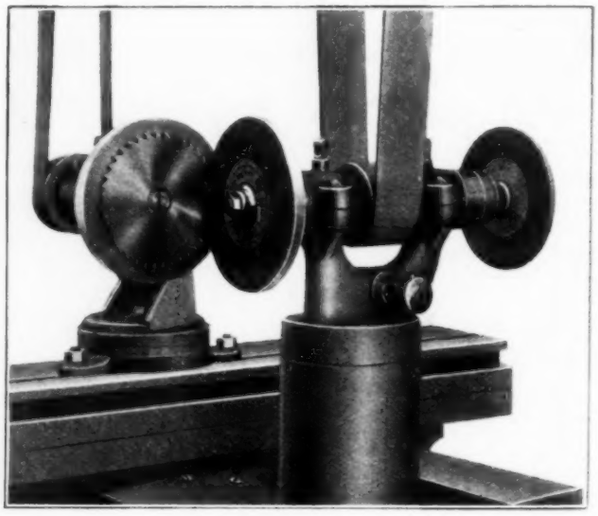


FIG. 2

TWO WAYS OF GRINDING MILLING SAWS

The fault of this method is the tendency to glaze and heat. In many cases the heat is enough to draw the temper of the saw. The long surface of wheel contact causes this and prevents rapid cutting.

Fig. 2 shows what I consider a better way. An ordinary disk wheel of rather course grain and free cutting is used. The saw is fed across the face of the wheel. I will guarantee to cut four saws to size in this way in the same time it takes to cut one the other way, and the saws will not be uncomfortably warm when finished either. The finish is also decidedly better. For a saw four inches in diameter and in the neighborhood of ⅛ or 3/16 inch in thickness, our practice is to make it 0.004 inch thinner in the center than at the circumference. That is a clearance of 0.002 inch on a side.

One of the best ways to measure the thickness of a saw while grinding to size is to use a micrometer with a sliding anvil. For instance, you want to grind a saw to a thickness of 3/16 of an inch, and the thickness of the face-plate to which the saw is clamped is less than an inch. (If your face-plate isn't the same thickness all around make it so, and save trouble.) Take an adjustable micrometer that will measure from naught to two inches; set it to read naught, pull back the adjustable anvil, put the micrometer over the edge of the face-plate, and push in the anvil and clamp. Now you can read the measurements direct on the barrel without any bother in subtracting the thickness of the plate. That is, the saw should measure, when measured with its own thickness and that of the face-plate, just 0.1875 or 3/16 of an inch.

It is very likely that many are familiar with this method, but I often find men who are not. This same principle is also very convenient on lots of other tool-room work. I have a micrometer that measures from naught to six inches, the sliding anvil having a movement of five inches, which is used almost constantly in this way on various jobs.

Based on the period extending from 1904 to 1906 it appears that the annual number of patents in the electrical field in Europe amounts to about 5000. An estimate is made which relates to the number of patents secured each year by inventors belonging to their respective countries. Thus we have for England and colonies, 750; Germany, 700; France, 400; Austria, 200; Italy, 180; Hungary, 130; Switzerland, 120; Belgium, 90; Denmark, 90; Sweden, 90; Spain, 35; Australia, 35; Norway, 30; Portugal, 15, making a total of 4915 patents taken out annually.—*Electrical Review.*

Shrinkage of Wood Lengthwise and Distortion of Steel in Hardening

By E. T. Strong

The action of tool steel in the process of hardening has come in for considerable attention of late, and to me it is a question of increasing interest and instruction, for all of the many different opinions and observations which have been recorded. This knowledge cannot come by close observation, and to make it more dependable the toolmaker should also do the hardening; but this is not the case nearly as often as it ought to be.

My attention was quite forcibly called

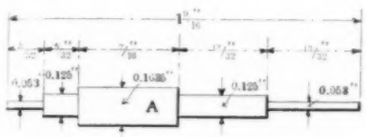


FIG. 1. EXTENSIOMETER SPINDLE

to this matter of hardening distortion recently owing to having six extensiometer spindles to make from tool steel. After making three, I was called upon to have the section *A*, Fig. 1, hardened. This section makes contact with a bar attached to the sample on the testing machine and was to be as near one-half an inch in circumference as I could make it. The ratio of this diameter of the spindle to the graduated dial was 1 to 24, so that any error in uniformity of this diameter was very apparent when taken from the circumference and multiplied 24 times, as the readings from the dial would show.

I made the remainder the same size as

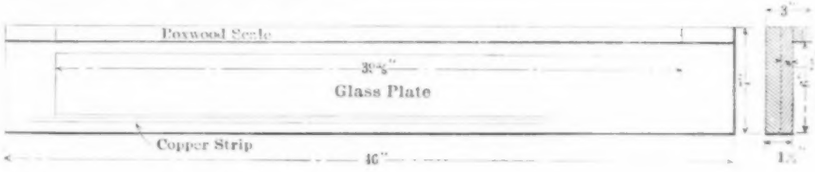


FIG. 2. PLAN OF INSTRUMENT

the three already made, namely, 0.1635 inch, and proceeded to harden them, after carefully checking their diameters. The pieces were heated in a gas flame and quenched in water, care being taken not to harden the small spindle ends. After quenching and polishing the surface with crocus, it was found that all of them were from 0.0002 to 0.0004 inch large in the hardened portion.

Wood Shrinking Lengthwise

Apropos of this question of shrinkage in metals, I wish to introduce the one of shrinkage of wood in the direction of its length or grain. Such information as I have received on this matter has been that it does not shrink in its length, but I am now prepared to prove that it does, or that some woods do. There are some wooden mounts for electrical instruments which have come under my notice that show this quite conclusively.

The general plan of these mounts will be apparent from the end view, Fig. 2, which is of a built-up pattern. There are placed on this mount a wooden scale, glass plate and copper strip, as indicated; in addition there are a number of wires stretched taut longitudinally over the glass plate and anchored on the wood. These anchors abut against the ends of the plate, as the glass plates and the wires must be a definite length. The plates are held from any side motion by small tacks on each side. The scale and copper strip are held by screws about 8 inches apart.

These instruments were received from a well known scientific-instrument company, of England, about the middle of the past summer. Some weeks ago one of these instruments was brought to me for repairs, the trouble being that the glass plate was standing up in the middle about 1¼ inches from the board, having seemingly grown in length. An inspection proved that the wood had shrunk, as the scale and copper strip were both buckled between the screws. The wires were also very slack. I had to remove the anchors at one end of the plate and cut 3/32 inch off of it. Thinking this might be an isolated case, a close watch was kept on the remaining ones of like kind (ten in all), and the result is that all of them are shrinking in length.

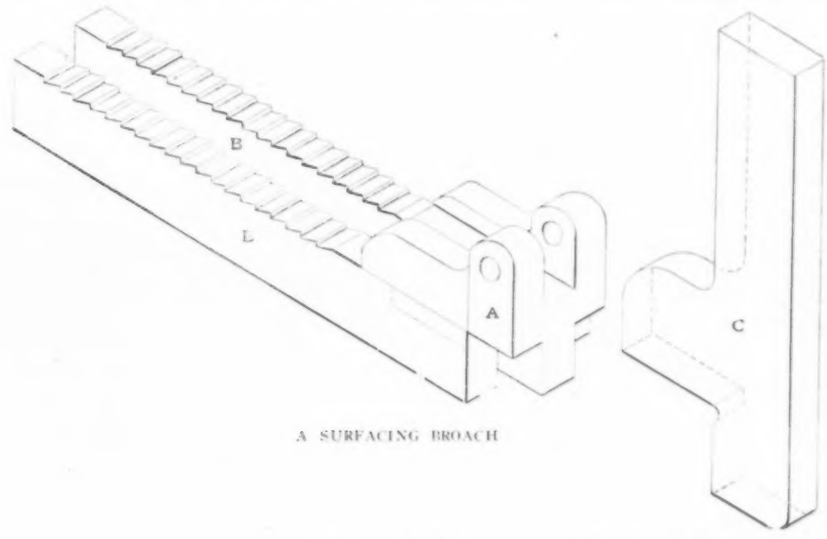
All parts connected to these mounts are proving so conclusively that such is the case, that orders are to be placed for new mounts to take the place of the present ones.

As these instruments are of a scientific nature, it would seem that if this phenomenon was generally known, the builders would not have used a wood that is subject to such changes. On the other hand, if it is known, it would seem that there was gross carelessness in the use of such material. The latter does not seem probable as the manufacturers would be recognized everywhere, were I to name them, as being reliable in every particular.

Are there any who can furnish data on this subject?

A Surfacing Broach

A novel way of facing off the under side of a loose jaw for a Bullard wrench was devised by their foreman, James Gabbi, not very long ago at their shop in East Providence, R. I. The milling machines were full of work and though more were ordered deliveries were slow, so he made use of a shaper in a way that will be new to most of us. The piece is shown at *A* and requires to be faced off on the lower side each side of the tongue.



A SURFACING BROACH

He made the two cutters *B B*, which are practically broaches, fastened them in the shaper vise at the proper distance apart, made the pusher *C*, and was ready for business. The piece is laid on top of the plain part of the cutters, the pusher *C* in the tool post of the ram comes along, fits into the slot and holds the piece down while it is being pushed over the teeth. The cutters are so inclined that the cut increases toward the back end; one pass of the piece, which means one stroke of the ram, faces the piece very nicely. It is practically the same as pushing a piece into or over a broach instead of pulling a broach through the work.

There ought to be other applications for this adaptation of the broaching principle.

Boring Bars for Turbine Castings

By T. M. Lowthian

The building of Parsons turbines requires some very large machine tools and which I shall refer to at a later date, but I wish here to call attention, more particularly, to boring machines, since one of the most important operations in the construction of a steam turbine is that of boring, and cutting out the grooves for the blades in the turbine casings. The machines are mostly of that design which carries a long self-acting boring bar rotated by large worm wheel and worm, and the one in question is 9 feet high from table top to center line of boring bar, which is capable of boring holes up to 17 feet diameter by 45 feet long.

This machine is provided with a boring bar 18 inches in diameter and 49 feet 6 inches long, but it is also arranged to take bars of smaller diameter according to the size of casing being dealt with.

Now as the sliding socket which carries the various cutter heads is fed along the bar by means of a screw of comparatively small diameter (extending the full length of the bar), it is evident that unless supported it would sag considerably as the bar rotates, but this difficulty is overcome by fitting adjustable supports to the screw as shown in Figs. 1 and 2 representing the side and end elevations of a boring bar, where *a* is the bar, *b* the feed screw, *c* a gun-metal pad fastened to a sheet steel band *d*.

To each end of band *d* is riveted a steel plate *e* ⅜ inch thick, and a bolt *h* passing through the ends of this band (and their respective plates) when tightened up, binds the band to the bar and so forms the support to the screw. Four of these are fitted along this bar.

Fig. 3 shows the end view of another bar which besides the feed screw *b* also carries a longitudinal shaft *s*; this shaft is for the purpose of feeding the tool out radially when cutting the grooves in the casing.

The mechanism for this is carried in the cutter head itself and consists of a worm carried on the shaft *s* and gearing into a spiral rack cut on an inclined piece which is fed along when the shaft is rotated, the inclined piece acting as a wedge and forcing the grooving tool out radially.

In another form the shaft *s* carries a bush screwed externally, which is threaded through an inclined piece and as before, the rotation of the shaft feeds the inclined piece along with a similar result.

Fig. 3 also shows the means adopted for supporting both the screw *b* and the shaft *s*, but in this case the steel band is in halves to facilitate removal when adjusting its position from one side of the cutter head to the other.

In Fig. 4 is another design of bar similar to that in Fig. 3 but in this case to save weakening the bar by cutting a second groove along it for the feed shaft *s*, the latter is placed outside the bar and a dovetail groove ¾ inch deep is planed along the bar for the reception of the bearings *t* (which are a sliding fit in the groove) and act as supports for the shaft *s*. Fig. 5 is a side elevation of one of the bearings *t*. These bearings *t* are adjustable along the bar, but as they cannot pass the cutter head they must be put in position before commencing the boring and grooving operations. Where this bar rotates in stays it is enveloped b ya circular hoop or bush large enough in diameter to cover the area occupied by the shaft *s*.

In the examples illustrated by Figs. 3 and 4, after one groove has been cut the wedge piece is returned to its original position, thus allowing the tool to be brought back clear of the groove (by means of a heavy spiral spring), then the cutter head is traversed along the bar by means of the feed screw, ready to cut out the next groove. The same cycle of operations is repeated until all the necessary grooves are cut.

The longitudinal movement of the cutter head along the bar when grooving is really a dividing motion, and this is obtained by means of a dividing plate keyed to that end of the screw furthest away from the driving headstock. In some cases a templet is used to set out the required pitch of the grooves, the cutter head being adjusted along the bar to bring the tool opposite each groove cut in the templet. By the above means the longitudinal and radial movements necessary to the tool when grooving can be got from either the inside or outside of the casing, the latter, of course, is the most desirable, the handles for operating the same being placed at the outer end of the bar.

One firm has a boring machine where the driving headstock itself is fed along the bed of the machine, the boring bar being attached to and rotated by this sliding head. In the case of large bars (24 inches diameter) they are made of cast iron and are made hollow to reduce the weight and are sometimes made in sections bolted together, the number of sections in use depending, of course, on the length of the work in hand at the time being.

Taking a mild steel-forged bar (also used on this machine), and which is illustrated by Figs. 6 and 7, the boring and grooving cutter heads can be clamped on in any position along the bar. In this design of bar one or more rectangular slots *v* are cut lengthwise of the bar, through

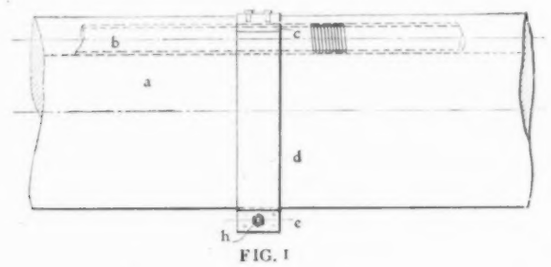


FIG. 1

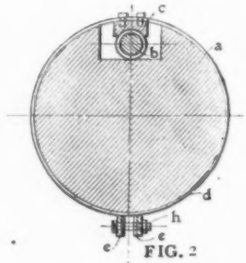


FIG. 2

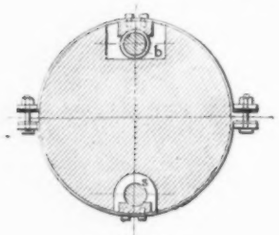


FIG. 3

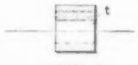


FIG. 5

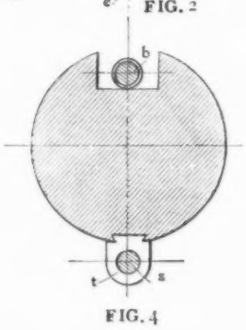
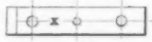


FIG. 4

BORING BARS FOR TURBINE CASES

FIG. 8



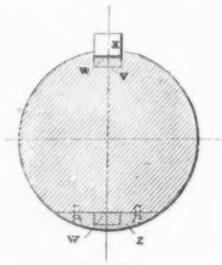


FIG. 7

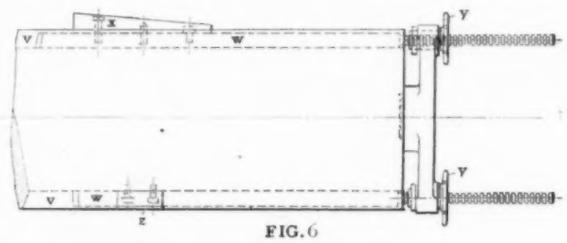


FIG. 6

MORE DETAILS OF THE BORING BAR

which slide steel rods *w* carrying wedge-shaped pieces *x* (one of these is shown in plan in Fig. 8), which are arranged to be fixed at different positions along the rods *w*.

The rods *w* have one end threaded and are fed longitudinally by means of star wheels *y* and tappet motion, the longitudinal motion to the rod and wedge piece forcing the tools out radially as already described.

After each groove is cut the rods *w* are moved back by hand to their former positions, thus bringing the tools clear of the grooves; the driving headstock is then fed along the bed a distance equal to the position for the next groove, and the same cycle of operations gone through until all grooves are cut.

The rods *w* are supported by gun metal blocks *z*, the bar having transverse slots cut through it in several places to receive same. Having these blocks flush with the periphery of the bar enables the boring heads to pass over them.

A Machine for Grinding the Ends of Springs

The making of pop safety valves requires that the ends of the springs be ground parallel to each other so as to give a good bearing on top of the valve seat and not cramp the seat as it lifts under the pressure of steam. After several experiments with machines for grinding these, the M. C. Hammett Company, Troy, N. Y., designed and built for its own use the machine shown. This shop, by the way, is on the site of and contains part of the old Richardson shop where pop valves had their beginning in the earlier days of steam engineering.

The springs are first tempered, then taken to the machine and clamped in the holder *I* to hold them firmly. The operator grasps handle *H* and swings the spring between the wheels, which are held in the chucks *A A*. The holder is mounted on the swinging frame *D;* attached to the lower end is the weight *G*, which acts as a pendulum and moves the springs in an arc past the faces of the wheels.

These wheels are mounted in the substantial heads *B B*, each of which has a hand wheel connected through bevel gears to the thrust blocks *C C*. The grinding spindles have ample bearings in the heads *B B;* but these do not take care of the thrust, as the spindle can be moved a limited distance through these bearings to bring the wheels up to the work. Turning the hand wheel to the left brings the thrust block *C* toward the head and forces the wheel toward the work, so that all adjusting is done without moving the main grinding head on the ways by by moving the thrust blocks, which are provided with special thrust collars to reduce friction.

In practice the wheels are set the required distance apart, the springs put in the holder, swung in between the wheels and the ends ground flat and to the right length. Several years' use has proved the value of this design, and it is quite possible that a similar machine may be useful in other lines of work.

Tool Holders for the Turret

This same shop uses for forming and turning tools a form of cutting-off tool and holders which is not common. Fig. 2 gives an idea of the general shape, which is practically a bar with two ears or projections. These are of cast iron and bolt against the face of a hexagon turret so that they are held as rigidly as the turret itself. The tools in Fig. 2 are used to cut piston rings off the usual long cylinder, but it differs from the usual way in having *A* at work on the inside of the ring and *B* on the outside so that the cuts meet in the center if they both start at the same time. Any chipping of the corners, as sometimes happens when the cut is entirely from the outside, is avoided.

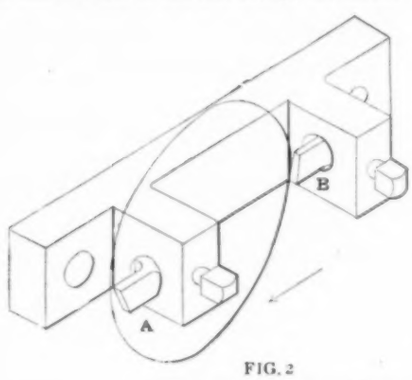


FIG. 2

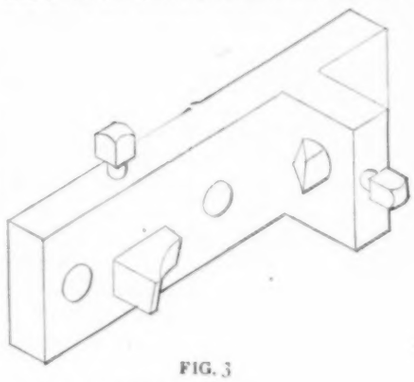


FIG. 3

TOOL HOLDERS TO BOLT TO THE FACE OF A TURRET

Fig. 3 shows another adaptation of this form of tool holder. Here one arm has been omitted; in its place is a forming tool for ball joints, while the arm at the right carries a tool which turns the outside of the joint.

This form of turret tool holder is cheaply made and allows the tools to be held firmly in a variety of positions.

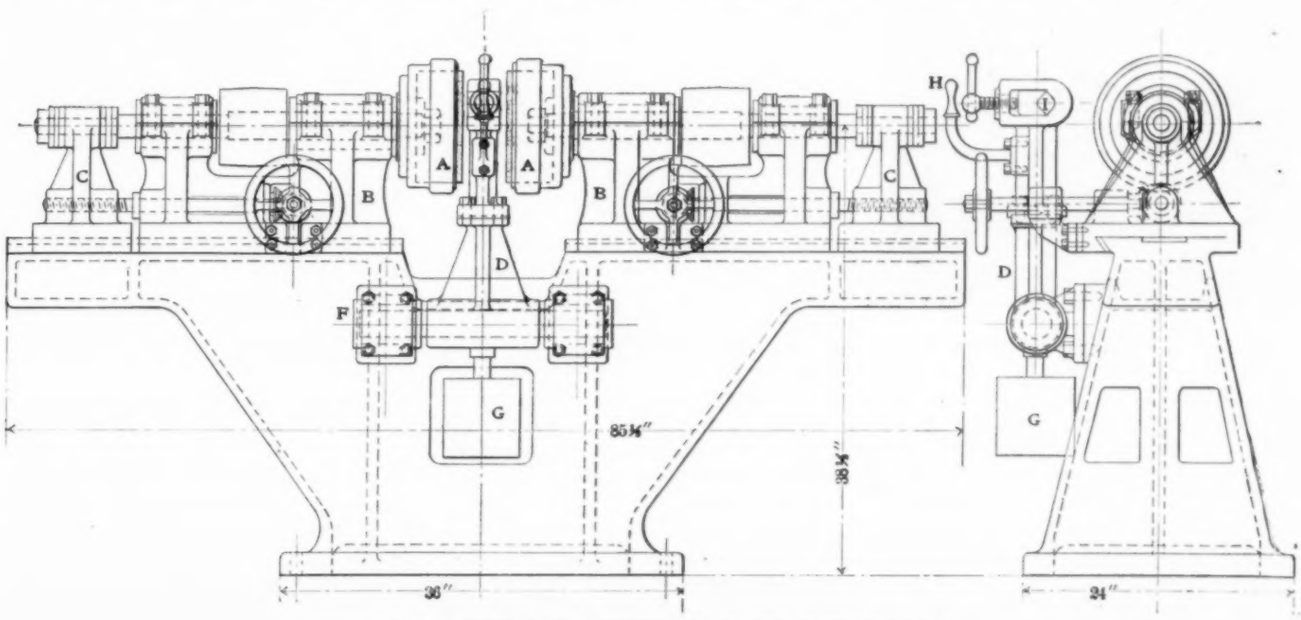


FIG. 1. DOUBLE ENDED GRINDER FOR SAFETY VALVE SPRINGS

Practical Letters From Our Readers

A Round Table Discussing Details of Modern Machine-shop and Drawing-office Methods, Practice and Economy

WE PAY FOR USEFUL IDEAS

Making Metallic Packing

Fig. 4 shows a forming lathe arranged for making metallic packing. The base *A* is fastened to the forming slide and supports the undercut tool *C* and the block *B* which holds the cutting-off tools. The boring is done with the tool *D*, which is

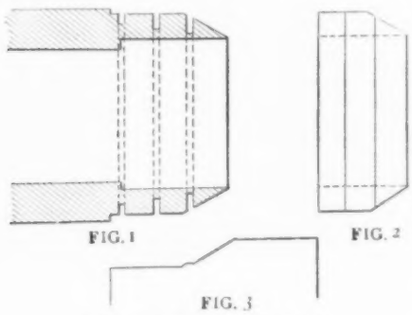


FIG. 1 FIG. 2

FIG. 3

THE WORK AND THE TOOL

fastened in the turret. The tool block *B* has a longitudinal adjustment so that the cutting-off tools may be set exactly. Fig. 2 shows the packing as assembled; three rings constitute a set. It will be noticed that the angle extends on the second ring. This necessitates the tool being made as shown in Fig. 3, and the first cutting-off tool set at the interruption of the angle, so

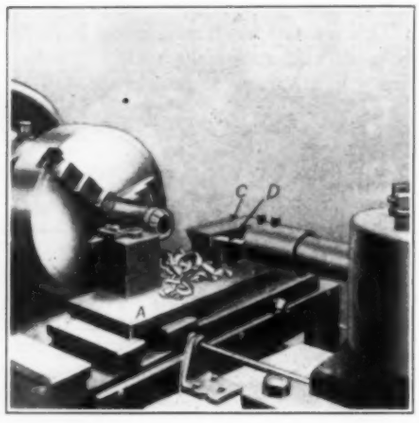


FIG. 4. MAKING METALLIC PACKING

that after the rings are cut off the angle will be continuous, as shown in Fig. 20 Fig. 1 shows a section of the stick of metal bored, turned and partly cut off.

The reason for making the supplementary base *A* was on account of making a set of tools for several different styles and sizes of packing. It is much cheaper to provide a base than to provide a base for each set of tools. When changing from one kind of packing to another, all that is necessary is to change tool block *B* and undercut tool *C*. The saving of this method of machining rings as compared with the method of casting separate rings and finishing is very noticeable.

St. Louis, Mo. W. T. H.

The Inverted V of the Lathe Bed —A Suggestion

The editorial at page 532, Vol. 30, Part 2, and Professor Sweet's rejoinder at page 173, remind me that I am also out of the lathe business, so I may safely give away one of the points in which the supremacy of the American lathe bed is not so great as it seems. Under ordinary conditions the pressure on a lathe tool is downward, to the right, or toward the footstock, and toward the front, or the workman. Just what the proportions of these pressures ordinarily are no one knows. To be sure Professor Nicholson found a sort of average of about 10 per cent. of the cutting

FIG. 1 FIG. 2

A SUGGESTION FOR LATHE V'S

pressure as needed to hold the tool up to the cut, and Fred Taylor says that the feeding mechanism should be as strong as the driving mechanism. Between these two one man's guess is as good as another, and whatever his guess, he is as sure to be sometimes right; like the clock that has run down, it is sure to be right twice a day.

But what I want to get at is that there is almost sure to be more wear on one side of the V than the other. The effect of this (see Fig. 1) is to throw the whole carriage to one side, toward the front, and consequently to turn the work large by twice the distance *D* of Fig 1 at the point where this particular amount of wear has taken place.

Now for a remedy. I do not expect to see this adopted, though I should not be surprised to see someone rush off and get it patented. Fig. 2 solves the whole difficulty. Make the two angles such that, when the distance *A* has been worn off the face of the V toward the back of the lathe, and the distance *B* off the front face, the vertical distances *C C* will be equal. This can be done easily just as soon as we know the relative values of the vertical and horizontal pressures on the tool and, as I said before, one man's guess is as good as another's.

Fitchburg, Mass. ENTROPY.

A Peculiar Accident to a Gas Pipe

A rather peculiar accident happened in our factory a short time ago, and since

FIG. 1. GAS PIPE CUT INTO BY A LINE SHAFT

it had dangerous possibilities it may be of interest to others who have similar conditions.

On the third floor of the building there is a jack shaft which supplies power for the floor above. This shaft is 2 7/16 inches in diameter and runs at 112 revolutions per minute. At right angles to the shaft and a few inches above it hangs a 1-inch gas pipe supplying that floor. Escaping gas was first noticed on a Saturday afternoon when the factory was closed. Some men at work on a repair job reported it, but could not find the leak. On Sunday, the watchman noticed the odor of gas and shut off the supply. On Monday, during the noon hour, the leak was noticed again, the gas having been turned on, and a thorough search

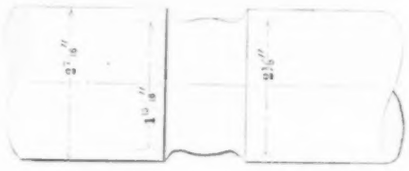


FIG. 2. SHAFT CUT INTO BY A GAS PIPE

revealed the fact that the gas pipe had fallen from its hangers and lay across the shaft. An examination brought to light the peculiar hole shown in the half-tone, Fig. 1. The shaft was in such a position as to make a photograph of it difficult to obtain, hence the sketch, Fig. 2. The fact that previous to that Saturday afternoon no escaping gas had been noticed would seem to indicate that when the

shaft was rotating there was a tight joint between it and the pipe; but when not in motion the gas leaked through some of the grooves cut by the pipe.

It is hard to say just how long these conditions had existed, or what the result would have been if the pipe had been cut in two and the full supply of gas poured into the room, where open jets were burning and which was filled with employees. It is safe to say, however, that it would have been dangerous to both life and property.

RAYMOND C. WILLIAMS.

Worcester, Mass.

Preparing Stock for the Screw Machine

It would seem to me that with his rod-pointing tool, page 139, for preparing stock for the screw machine Mr. Mason is going to a lot of unnecessary expense and time.

In the screw-machine department where I am employed making a medium grade of work, all that we find necessary is to rough grind both ends of the stock by hand, simply beveling the end. The emery wheel is always running and is always ready for any size and shape of stock of which we use flat, round, square and hexagon in 10- and 20-foot lengths.

Lowell, Mass. PAUL W. ABBOTT.

Index Drilling Some Small Steel Caps

Having six small tool-steel caps to make for a model as shown in Fig. 1, the manner in which the 10 holes were equally spaced and drilled with a No. 55 drill may be of interest. The only milling machine available was a No. 1 Brown & Sharpe universal, the speed of which was too slow to

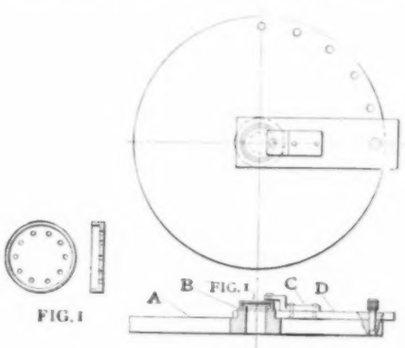


FIG. 1

FIG. 2

THE WORK AND THE FIXTURE

accomplish results by using the dividing head.

An index plate *A*, Fig. 2, containing 20 holes, was borrowed from this machine. A soft-steel plug *B* with a 3/8-inch hole through the center was made a *light* drive fit in this index plate. *C*, which carries the drill bushing, is located to the proper center distance and riveted to the flat piece of stock *D*, which revolves on the plug *B*, the opposite end carrying a pin with which the divisions are made by using every second hole. The piece to be drilled is lightly driven on the plug *E*, the hole in this plug permitting the drilled piece to be easily removed; it is driven off with a light hammer and a small piece of hard wood. *D* is removed before this latter operation.

Lansing, Mich. GEO. HUBER.

A Rapid Threading Job in the Lathe

Fig. 1 shows the piece to be threaded. It is of machinery steel about 36 inches long, centered and straightened in the usual manner, with a collar and short end for driving, the collar and ends being finished in the ordinary manner. On the end where the driver is placed a V-groove

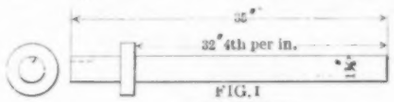


FIG. 1

FIG. 2

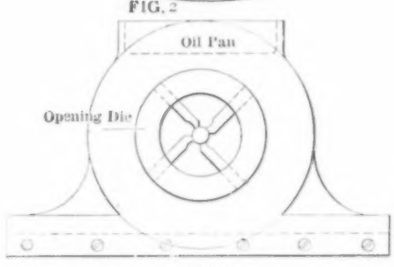


FIG. 3

THE WORK AND THE DIE

is chipped, into which is driven the hardened-steel key, as shown, there being enough stock on the screw at the end where the driver is keyed to turn out the groove afterward.

Fig. 2 shows the kind of driver used, as it was found that the ordinary dog was wholly inadequate to carry the strain placed upon it.

Fig. 3 shows the style of die holder that was used, of the opening and closing style, and made to fit on the lathe carriage in place of the cross slide so that the center of the die would line up with the lathe centers. On the top of the die head was an oil pan, cast with suitable oil grooves to keep the dies flooded with oil when cutting.

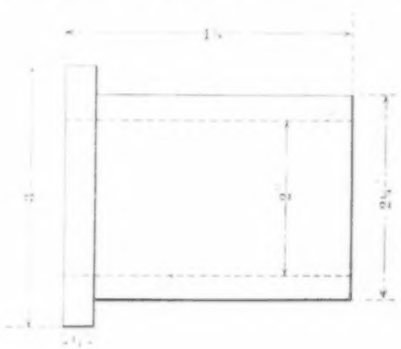
In operation the driver was first tightly keyed to the work and the work turned to size by means of blank cutting dies in the die head in place of the threading dies. I think two cuts were taken to size the screws, the lathe feed being as coarse as necessary to turn the work rapidly. It will be readily understood that a long dead center is required in order to close the dies before starting the cut. After the pieces were turned to the right size, the cutting dies were changed for the threading dies, which were adjusted to the proper size, the lathe being geared to cut the same pitch as the dies, the feed thrown in on the lead screw and the lathe started. If the lathe is powerful enough, the die will traverse the length of the place to be threaded, leaving a full square thread 1½ inches diameter at one cut. The screws are then finished near the collar on the last few threads that the die would not cut full, filed up and polished, the short end turned, and a fine thread cut on the end in another lathe. Where there are a large number of pieces of the same kind to be done, this makes a very fair job at very much less cost than possible if done in the usual way. The dies were found to work better with a good deal of top rake; even then a tooth would snap occasionally, but on the whole the job was very successful

Where the screws must be very smooth and accurate, this method would hardly answer; but there are many places where screws cut in this manner could be used with good results, as, for instance, rock-drill feed screws, for which I believe these were used.

Hartford, Conn. E. S. WILLIAMS.

Shrinking a Die

The line cut gives the approximate sizes of a cutting and forming die I saw recently in the shop of Edward Board in Philadelphia. After hardening, the piece was found to be 0.004 inch out of round and 0.008 inch larger than when it was turned. In order to save the piece it was necessary to reduce the size and bring it nearer round. The piece was first drawn to a light straw color. A heavy cast-iron collar was turned 0.01 smaller than the average size of the die. This was heated so hot that it could not be handled but not



SHRINKING A DIE

hot enough to further draw the temper. The collar was then forced on the die under an arbor press. The two pieces were then heated till the die was drawn to a dark straw and the two pieces were allowed to cool. After cooling it was found that the die had been reduced 0.009 inch in diameter and was of suitable size to finish grind. It seems to me that this is

something new, but, suppose the piece had gone small, I wonder how safe it would have been to heat the die slightly and drive a plug 0.01 large into it?

New York. E. A. DIXIE.

Drilling Ball End Work

There was in the shop a large quantity of drill-press work of a class represented by the piece shown at Fig. 1 in which a hole is drilled through the ball. It is necessary that the hole be central with the ball and at right angles to the axis of the screw. There were various sizes of balls and as many shapes and sizes of shanks and the practice had been to drill them in a jig like that in Fig. 2.

This consists of a gray-iron base *a* to which are attached the V-block *b* and drill guide *c*. Some of the jigs had an adjustable stop screw *d* for adjusting the position of the work. Some also had a latch to swing over the shank of work to hold it down, as the drill had a distressing tendency to cause the outer end of the work to tip up, thus drilling the hole out of square. The diameter of the ball was rarely the same as that of the shoulder, so that the V-block must be worked out at one point to suit the work. It was difficult to do this so as to keep the hole square.

The practice also was to make the drill guide *c* of tool steel and harden the whole piece instead of using a bushing that could easily be renewed.

There was a large assortment of these jigs and a good share of the time they were being repaired.

Finally I designed and built the jig shown by Figs. 3 and 4. This worked so well that another one was made just like it and the two jigs easily handled all such work that came along.

In Fig. 4 the gray-iron base *a* is grooved a driving fit for the bottom of piece *b*, which is of machine steel and secured to the base by two substantial dowels as shown. The plunger *c* has a vertical movement in hardened bushings and is actuated by the lever *d* which is fulcrumed on pin *e*, the pin being hardened and working in a hardened bushing in piece *b*. The hole for pin *f* is a driving fit in the plunger and is slightly elongated in the lever.

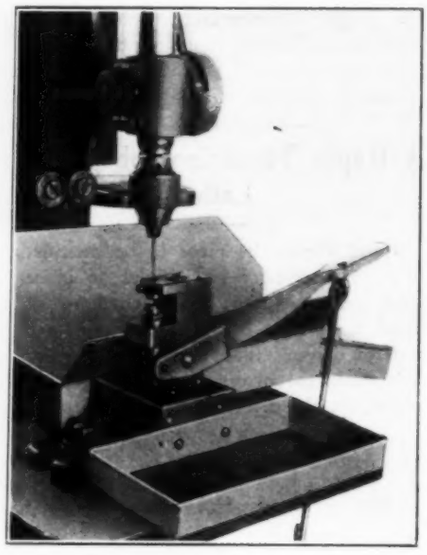


FIG. 3. THE JIG IN POSITION

The upper end of plunger *c* is tapped out for a plug *g* and the plate *h* is bored in line for the drill bushing *j*. A section on *k-l* shows how the bushing and plug are recessed to fit the work.

The spherical seat is bored out at the time the hole is drilled which assures the hole being central in the work.

The cross hole which fits the shoulder of the work is worked out with an end mill and upon the accuracy of this depends the squareness of the hole with the axis of thread.

The rod *m* attached to the lever connects with a pedal conveniently located for the right foot. A long coiled spring attached to the pedal keeps the jig normally open. A pointed screw (not shown in sketch) locates the bushing *j*. It is only necessary to make bushing *j* and plug *g* in order to accommodate any job within the range of the jig.

In use the work is inserted with the left hand, clamped and held by the foot on the pedal and the right hand used to work the drill press. After the photo was taken an adjustable compressed air pipe was attached which blew the work out of the jig into the pan in the rear as soon as the foot released it. It also kept the jig entirely free of chips.

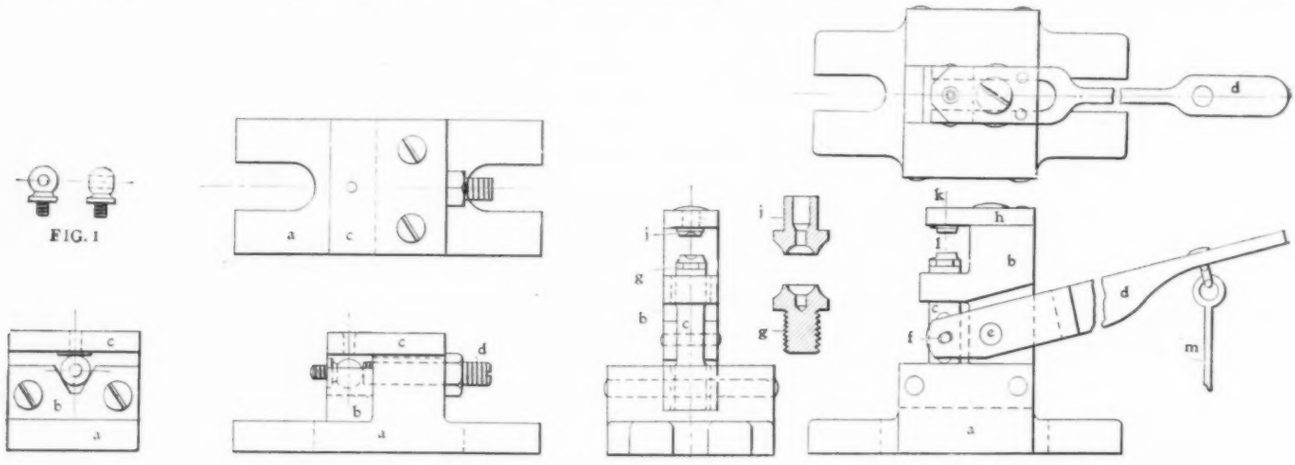
This device proved a very accurate and fast producer and very satisfactory in every way.

Waterville, Conn. RAYMOND GRANT.

Automatic Screw-machine Turning Tools

In the article under the above heading at page 207 it is recommended that non-adjustable back rests be bored out in the machine they are to be used in. That method I thought was forgotten, and I must say it would not go in most shops. Foremen as a rule look a little ahead and order the necessary tools and rests to be ready when the machine is through with the present job. For my part I would not allow a toolmaker the use of a machine every time I wanted a rest or bushing. We must have tools with parts interchangeable and adjustable these days and save machines standing idle waiting for tools. I hope readers won't think that I am not aware that quite a number have been idle for a few months that are not waiting for tools. Just look back to bicycle days. We always had a number of machines waiting to have the turret lined up with the spindle because we were using tools with round bushings and non-adjustable rests. The tools we could not line up so the machines we had to. We had the same trouble then with drill and mill holders, also tap and die holders.

Only a few weeks ago a foreman wrote



a letter, published at page 959, Vol. 30, Part 2, pleading for cheap lathes in place of automatics. He stated that by the time he got the necessary special tools to start the job he would have it half done in his lathes. I can see what his trouble is. He finds out what he must have, as his tools are not suitable for the job. He goes to the tool department and asks the foreman to rush the necessary tools out for him by, say Monday morning. He is told "we are awful busy, how will Friday do. That is about the best we can do." He looks at his old lathes right away, and sees he can have the job finished before he gets the tools. He looks up another job for his automatics or begins using make-shift tools and gets bad work. I am glad I am a toolmaker and can turn in and help myself when necessary and not be altogether dependent on the toolroom.

Stamford, Conn. McK.

Test Indicator

The accompanying illustrations show a test indicator for inside or outside work, which can be used on lathe, shaper, planer, or in fact, anywhere a tool of this description is wanted. It is very accurate, and having used it for the past eight years and loaned it to a number of my shopmates, it is upon their approval that I am sending details of it to the readers of the AMERICAN MACHINIST.

Bridgeport, Conn. G. T. ALDIN.

Limit of Accuracy in Calculations

After reading the article on "Limit of Accuracy in Calculation," on page 64, I feel compelled to say more about my methods of working, Mr. Logue seems to have overlooked the main point which I put forward. My contention is, you are justified in using a slide rule so long as the percentage of inaccuracy which may result from its use is not greater than the percentage of error from other factors.

I do not advocate the slide rule for all calculations; indeed, I do not use it for more than half of my own work. If an answer is likely to be one-thousandth part of an inch wrong, and such an error is too great for the class of work in hand, the rule should not be used except as a check. But because I could not obtain the value of, say, the centers of a large pair of gears accurately enough for machining purposes, I would be foolish to throw it at the back of my drawer and never use it at all. When running out the

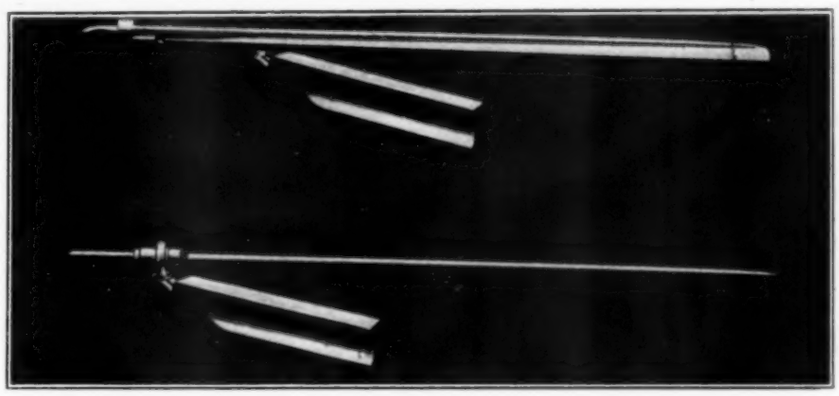


FIG. 1. TEST INDICATOR

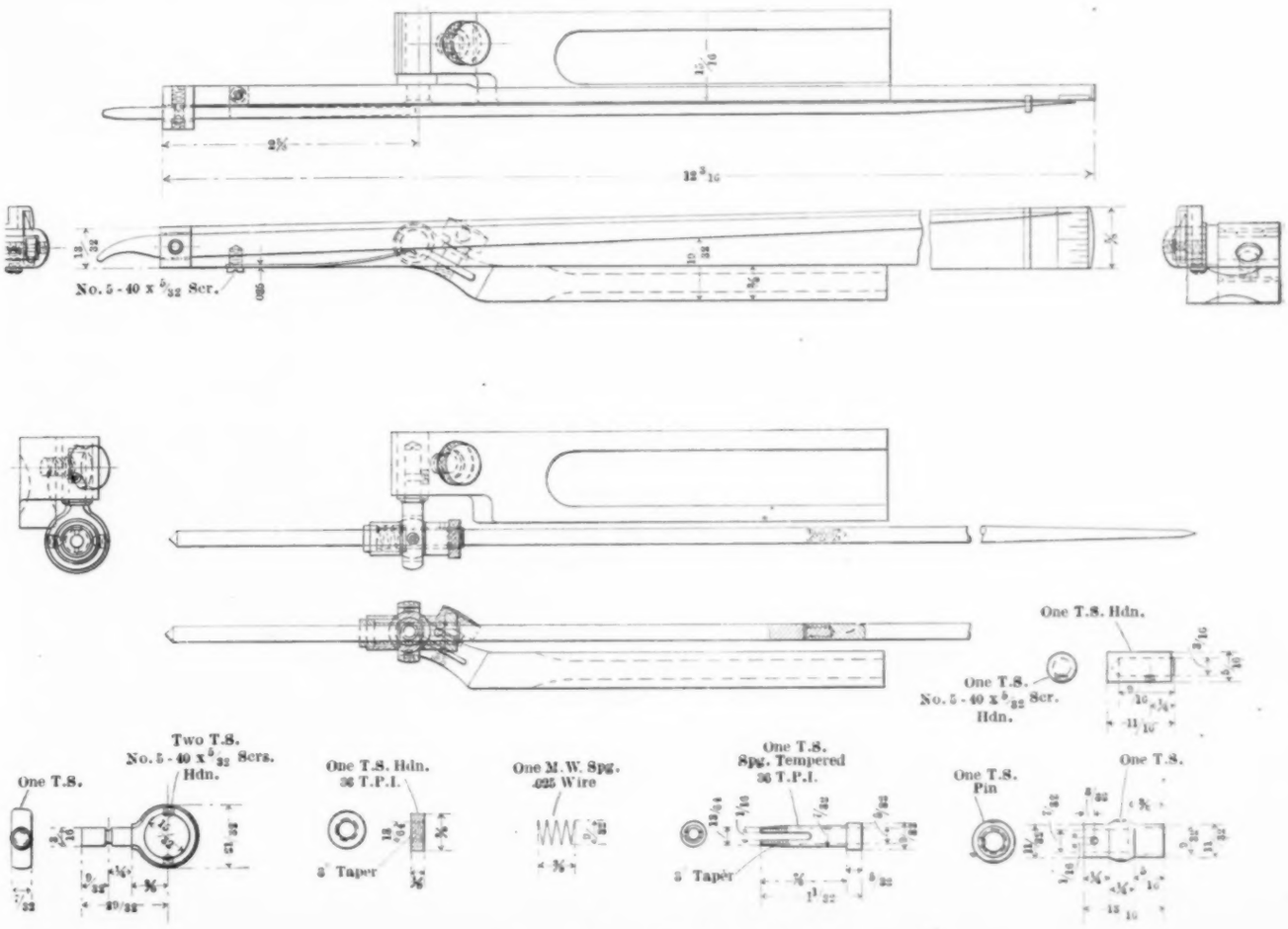


FIG. 2. TEST INDICATOR DETAILS

weights of castings, forgings, etc., the approximations made as to hollows and irregular surfaces might affect the answer more than the discrepancies of the slide rule.

Did you ever hear of the electrician who excused himself for using the quantity 3 for π by pointing out that draftsmen ran out the breaking stress in a structure to four decimal places and then used a factor of safety of four or five; they were never sure which was right. Do you ever find accurately the stresses in the flanges of a shearing-machine frame? A draftsman obtains a certain figure and would stake his reputation on its accuracy. To begin with the pressure, its value depends on the maximum area in shear, which, in turn, depends on the cutter, the thickness of the plate and the penetration. Different writers use values of the latter which vary by 33 per cent. for any given thickness of plate. Again, the shearing stress of the plate per square inch is not known with great accuracy. Also errors in molding affecting the thickness of metal, flaws in the metal and the general quality of the metal, so affect the safe load which may be applied, that the comparatively small errors of the slide rule are negligible.

In conclusion let me point out to Mr. Logue the necessity of roughly analyzing the work in hand and of using the most efficient method of obtaining an answer. Sometimes it is by ordinary calculation, sometimes by means of the slide rule, or by a combination of both methods.

Concerning the objection of checking slide-rule answers, it appears to apply equally to both methods. The only safe way of calculating is to write down each part step by step, so that any one can be checked without going over the whole.

E. M. Senygur.

Manchester, England.

Apprentice Training ve sus Machine-operator Training

On page 205 I notice Clinton Alvord's remarks under the above heading. I, for one, am in sympathy with him in his opinion and in the methods he adopted regarding apprentices.

I took charge of a shop a few years ago where they built a well known engine, and I found there a large number of boys and young men whose ages varied from 15 to 20 years. They were employed under an apprenticeship system at prices from 5 to 20 cents per hour. This system had been installed by the manager, who explained that the boys were the cheapest labor to be obtained. Yet the product of the plant was produced at a loss to the company, and I was expected to put a stop to any further decrease in the firm's bank account. Upon investigation I found a sort of a freemasonry existing among the boys, which was impossible to allow to exist and get good results. After trying various methods to instill into their minds that shop hours were not for base ball arguments and other disputes, I adopted the methods mentioned by Mr. Alvord. By breaking intelligent laboring men into the operating of various tools the trouble was stopped, also the firm's bank account shrinkage, and 30 per cent. more work was produced, also that smile that won't come off.

I might state that most of the work was of a micrometer nature at that.

Philadelphia, Penn. P. E. Tomb

Inside Caliper Rest

In calipering a hole it is necessary that the line that joins the points of the caliper legs should stand at right angles to the axis, or center line, of the hole, as

FIG. 1

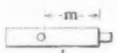


FIG. 4

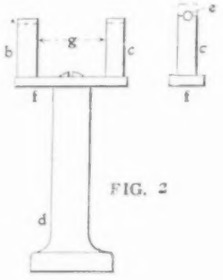


FIG. 2

FIG. 3

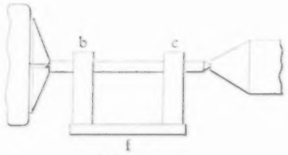


FIG. 5

INSIDE CALIPER REST

well as to intersect this line. The latter point is easily determined by noting the absence of vibration from side to side, which occurs when the calipers are set a trifle under size, but there does not seem to be any good way of insuring the first named condition unless there is a shoulder in the hole, against which the caliper points may abut. Many of the holes that I have to bore in the lathe with a slide rest tool are in comparatively thin material, and I felt the need of some sort of a device to hold the calipers so that the line joining the points should be parallel with the face plate.

My inside spring calipers are of a well known make, and have for their pivot, or joint, the spool-shaped affair shown in Fig. 1. This spool I chucked and drilled through its entire length, and into this hole drove a round steel wire that projected about ¼ inch from each end of the spool. The rest for the calipers is shown in Fig. 2, and is built up of several pieces of steel riveted and screwed together, to form a fork in which the wire *a* Fig. 1 may be laid. The rest is of such a hight that when it stands on the cross slide of my slide rest, the center of the half round opening *e* comes at the hight of the lathe centers. Of course it is a self-evident proposition that if the pivot of the calipers is at the hight of the centers, and the caliper legs are both the same length, then the ends of these legs must be at the same distance from the face plate when they are calipering a hole in chucked work.

It is a comparatively easy thing to get the opening *e* at the hight of the centers if the base *d* is the last part made. The plate *f* is the first thing to make, this being laid out so the distance *g* Fig. 2 is slightly greater than *h* Fig. 1. The studs *b* and *c* are made by first drilling crosswise through a piece of drill rod with a drill one or two sizes smaller than *a* Fig. 1, and then turning a shoulder on the end so that the distance *m* Fig. 4 is alike for both studs, and is not less than half of the greatest value ever assumed by *k* Fig. 3. The studs *b* and *c* are now cut off from the parent rod, but longer than their final length, so as to leave the cross holes complete, and are riveted into the plate *f*, a wire that fits the cross holes being inserted therein during the riveting to insure approximate alinement. After riveting, a rose reamer the size of *a* Fig. 1 is run through the cross holes in *b* and *c* to finish them to size and make the alinement complete. Having got thus far, a wire the size of *a* can be pointed at the end so as to rest in the female tail center, and the other end held in a wire chuck in the live spindle. On this wire the apparatus can be hung, as shown in Fig. 5, the plate *f* dangling below, while a pair of sliding-jaw calipers placed between *f* and the slide rest gives the length for the base *d* Fig. 2. After this the tops of *b* and *c* may be cut off so as to leave half of the cross holes in which to rest the wire *a*.

Brooklyn, N. Y. Walter Gribben.

Cost Accounting Under Reduced Output

Your editorial, on page 256, brings out very plainly the folly of confounding actual with standard costs. Actual cost is made up of two factors; one is constant, the other is variable. The constant factor is what the operation or finished product should cost on *a priori* determined grounds. The variable factor is the momentary efficiency of the man, or machine, or department, or plant.

In my own practice I first standardize every item that enters into cost on the basis of normal prices, normal output and 100 per cent. efficiency. To obtain the actual cost of work to the standard costs to be undertaken in March, 1908, I add the

inefficiency per cent. determined for February.

AN EXAMPLE OF STANDARD COSTS

Time, 8 hours.

Standards	Special Case.	Standard Cost Special Case.
Rate of man per hour	$0.40	$3.20
Machine rate per hour	0.80	6.40
Surcharge on wages for general expense	45 percent.	1.44
Materials required		12.00
Total standard cost		$23.04

This cost remains standard until changed, preferably at some predetermined revisional date; end of fiscal year, for instance.

ACTUAL COSTS IN MARCH, 1908

Standard cost	$23.04
Shop efficiency in February, 1908, 80 percent. Amount to be added to Standard, 25 percent.	5 61
Actual cost in March, 1908	$28.65

ACTUAL COST IN MARCH 1907

Standard cost	$23.04
Shop efficieney in February 1907, 125 percent. Amount to be deducted from Standard, 20 percent	5.61
Actual cost in March, 1907	$17.43

PROFIT AND LOSS

Current selling price in March, 1907	$30.00
Actual cost, March, 1907	17.43
Profit	12.57
Current selling price in March, 1908	$25.00
Actual cost	28.65
Loss	$ 3.65

Efficiency was high in March, 1907, because the factory was, perhaps, working on double shift, thus doubling the efficiency of the machines and plant as a whole. Efficiency will be low in March, 1908, because in February the plant was running on short time.

This system is ideal, not only for all accounting, but also for all operation. An efficiency standard is set up for every separate man, every machine, every tool, every operation; for all materials used, for every foreman and every department, as well as for the shop as a whole. Thus there is no one who does not become interested in efficiency. It is, moreover, easy to reward men on an efficiency basis.

There is just one essential, namely, correct standards must be established. From an operating and competitive point of view, if not from an accounting standpoint, it is misleading and also disastrous to credit a man, or foreman, or department with 100 per cent. efficiency when in fact the efficiency is only 40 per cent., as is too often the case. A perfected efficiency system of accounting and of governing operations requires less clerical force, less bookkeeping and less timekeeping than the usual methods.

HARRINGTON EMERSON.

New York City.

Drafting-room Kink

The writer does not claim to be the originator of the idea in the following suggestion, but has found it a very useful drafting-room "kink" not generally known.

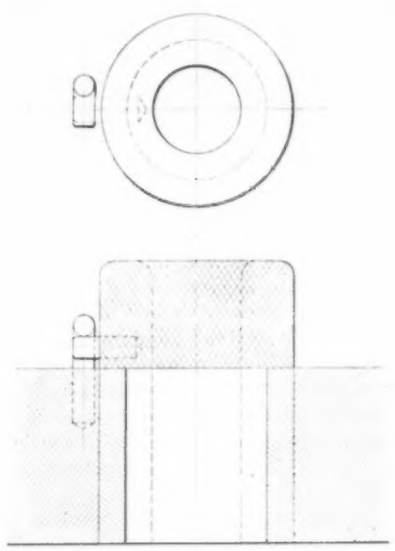
On any tabulations made on tracing cloth or paper, blueprints of which are to be made, put the necessary form lines on the opposite side of the sheet from the letters or figures. Any erasures in the latter can then be made without disturbing the form, and a much plainer and neater blueprint will be the result.

Buffalo, N. Y. J. C. AUSTIN.

Movable Bushings

Mr. Baker, in his article at page 101, fails to point out the fact that in Mr. Metzroth's design of jig bushings shown at page 595, Vol. 30, Part 2, he has not provided any means of holding the bushing down in the jig while withdrawing the drill.

Of course Mr. Baker has taken care of



MOVABLE BUSHING

this in his design, but as he has not allowed any movement and evidently does not nurl the head, it is a hard matter to remove the bushings after they get warm and expand, which everybody that has ever used slip bushings know they will do.

The method of holding the bushings shown herewith is the best one I have ever seen, besides being cheaper than either one shown in the articles referred to. Here you have the advantage of turning the bushing almost a full revolution when removing it. I never make the head shorter than 5/8 inch and larger bushings have heads in proportion. For reamed holes up to 1/2 inch I believe the best plan is to have only one bushing the size of the reamer, the work being first spotted with a drill that fits the bushing, then drilled with a smaller drill, allowing just enough for the reamer. This method is in use in a large factory where thousands of holes are accurately drilled and reamed in this manner, and has proven to be very satisfactory. C. I. INNIS.

Cleveland, O.

Inserted-tooth Cutters

There has been some little discussion in your columns on inserted-tooth milling cutters and the advantages of the different methods of holding the blades, etc., all referring to cutters having a cast-iron body. I was in a small shop in Chicago, where we did a varied line of work from designing and building special machinery down to whatever blacksmith work came our way. The job I refer to was milling the inside diameter and grinding the face of some twenty thousand dust rings for railway-journal boxes, and was, of course, taken at a certain price per piece and delivery guaranteed within a rather close time limit. The rings were made of cast iron, and were supposed to be soft, although we found many of them that an ordinary carbon tool would not make much impression on.

We decided to mill out the inside of the rings to the required diameter, designing a heavy fixture which was applied to a No. 4 B. & S. horizontal that we had in the shop. For a cutter we took one of the standard inserted-tooth mills, withdrew the blades and inserted Novo steel ones, chamfering them on the side which entered the work first. Then we put the cutter on the machine and started in. The blades stood up magnificently, and the rings began to come out in fine shape—for about 15 minutes—then the cutter struck a specially hard one, there was a grunt and a snap like a pistol shot, and although the arbor kept right on turning the cutter didn't. We shut the machine down and found that the cutter had broken in two straight across the body. There were no flaws visible, but we put it down to hard luck and sent out for two more new ones. As we were running night and day, we got the old blades out of the broken cutter and into one of the new ones at once and started up again. This one lasted about an hour and a half.

The boss then cut a piece off a 6-inch mild-steel bar that we had in the stock rack and put one of the toolmakers on the job of making a new body. As we were by this time way behind, the instructions were to stay with the job till it was done and running in the machine again. We did it, but I remember that it was just 27 hours straight time that we put in, eating "on the house" when we could get an opportunity, for the last cutter had broken the drive chain and stripped a gear or two when it went to pieces.

When we finally got the new steel body with a new set of blades into the machine it worked like a charm, and that same body is probably still doing duty today. The results proved to our satisfaction that the ordinary iron bodies of the standard cutters are not strong enough to stand up to the extremely high duty that was in this case imposed, and I should think there might be many similar instances.

Chicago, Ill. M. R. KAVANAGH.

AMERICAN MACHINIST

Issued Weekly by the

Hill Publishing Company

JOHN A. HILL, Pres. and Treas. ROBERT MCKEAN, Sec'y.

505 Pearl Street, New York.

Correspondence on mechanical subjects solicited and paid for. Name and address must always be given—not necessarily for publication.

Subscribers can have address changed at will. Give old and new addresses.

Subscription price $4 per year, postage prepaid, to any post office in United States, United States possessions and Mexico. $5.50 to Canada. $7 in all foreign countries except Europe and British possessions in Eastern Hemisphere.

The AMERICAN MACHINIST CO., LTD., 6 Bouverie St., London, E. C., will serve all subscriptions for Europe and British possessions in Eastern Hemisphere. Price 30 Shillings for England. For all other countries in Eastern Hemisphere, 35 Shillings.

Entered at New York Post Office as mail matter of the second class.

Cable Address, "MACHINIST," N. Y.
Business Telegraph Code.

CIRCULATION STATEMENT

During 1907 *we printed and circulated* 1,151,500 *copies of the* AMERICAN MACHINIST. *Our circulation for February,* 1908, *was (weekly, monthly and European)* 93,750.

Mar. 5	36,750
Mar. 12	19,500
Mar. 19	19,500
Mar. 26	21,000

This paper reaches 36,750 *separate readers each month and* 19,500 *each week.*

None sent free regularly, no returns from news companies, no back numbers. Figures are live, net circulation.

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The Lesson of Cincinnati

We wonder how many of our readers have ever taken to heart the really inspiring lesson of Cincinnati, by which we refer to the repeated illustrations which are there found of the possibilities in life offered by the machine shop. As is well known, Cincinnati has come to be the leading town in the machine-tool industry. This distinction has been achieved during comparatively recent years, and is conspicuous as being the work of men who began life as apprentices, nearly all of whom can speak truthfully of the days when they "served their time." Of the numerous machine-tool shops of that town there are few in which one of the partners, and usually the leading one, is not a graduate from the bench and the lathe, these men having risen to positions of influence in the community and to prosperity and even wealth. Having a capital of a few dollars and much pluck, they embarked in lines of business in which most manufacturers could have seen but limited possibilities, but out of these they have carved what is fairly entitled to be called success in life. Going farther down the line the cases of advancement to positions of trust and responsibility, to say nothing of incomes which the average bank clerk would call handsome, are numerous and in them we find far more cases of men of the same type who have found in the machine shop an avenue of advancement which is scarcely equaled, we believe, in any other legitimate industry.

The case is more remarkable when we consider in how few cases the success of these concerns has been due to brilliant invention or to patent monopoly, the machines made being strictly competitive.

Not only is the progress of Cincinnati in the machine-tool industry the work of mechanics, but it is we believe, a success which would have been impossible by any other class of men. In no other line of industry, perhaps, do sales depend so largely upon merit, for no other manufacturer, of machinery at any rate, is favored with a class of customers who are just as good a judge of the merits of his product as he. More than this, in no other line of industry perhaps, is the margin of profit determined so entirely by the man in the shop. It is a common, and sometimes a contemptuous, remark of business men that profits are made in the office. There is, no doubt, much truth in this statement as applied to many lines of business, but in machine tools the only margin of profit that exists is that between the selling price which is fixed by the condition of the market, and the cost which is determined by the shop management. The office, of course, makes the sales and in so far as an increased volume of sales makes possible cheaper production, the office may be, in a sense, credited with the profits made; but with this limitation the profits or the absence of profits in the machine-tool industry is almost absolutely determined by the shop management.

These circumstances give the shop man his opportunity and Cincinnati is an impressive example of the manner in which he has taken advantage of it.

In one sense the machine-tool industry of the entire country is an illustration of the same thing, the chief difference lying in the more recent origin of the Cincinnati machine-tool shops. The history of machine-tool shops in other sections of the country, in their early days, was substantially the same, and perhaps the chief word of Cincinnati is to belie the croakings of many today who insist that with the growth of industry, conditions have so changed as to close the avenues which formerly were open. Looked at in this way the lesson taught by Cincinnati is that this is still the Land of Opportunity.

The Exception System of Management

The term "The Exception System" was, we believe, coined by Fred W. Taylor, in connection with his method of time-keeping, in which the men who enter the works in the morning on time pass through the gates without making any record whatever, the records being confined to those who are late and those who are absent, the result being a large reduction in the number of clerical entries necessary to make the records. The expression and the system are, however, of far wider application than this, and we believe that, to a large extent, they supply the key to successful management in a large sense.

We recently came across a conspicuous case of successful management under this system, and while many other examples of it exist, it is, nevertheless, worthy of notice.

A gentleman had been engaged as the works manager of a large and thoroughly modern factory by the president of the company, who understood his methods perfectly by reason of similar relations between them in former days, and, speaking of the results achieved by the manager in his new position, the president remarked that, while the results were remarkable, he really did not know how they were accomplished. The output of the factory had been increased, while the working force had been reduced, and, meanwhile, the mechanical construction of the product had been largely improved; but, speaking of the manager, the president remarked: "He really seems to have very little to do, his desk is never littered with papers, and if you call at his office you are more apt to find him with a cigar in his mouth and his feet on his desk than you are to find him doing any visible

work." This remark led us to discuss the subject with the manager, and he remarked that after getting the works in running shape he had made it a principle to devote his attention to unusual cases and, except in a general way, to no others. In the matter of production and cost, for example, so long as the parts came through in accordance with the figures which he had established, they and their records took their courses through the regular channels and without attention from him. His orders were that all exceptional cases, either in the direction of increased or decreased output, should be brought to his attention, and when brought to his attention they were immediately followed up. This, he said, was his practice regarding all of the numerous subjects that demand a manager's attention.

Another factory, which is known to all of our readers, is, judging by such observations as an outsider can make, managed on much the same lines, although very likely without formal recognition of the principle. While this factory is known to everybody as an example of superb management, the thing which has impressed us when going there is the fact that no one in a leading position seems to have much to do. Visitors are always welcome, and the managers always seem to have unlimited time to devote to their callers. When one leaves it is usually with an expression of regret that he cannot stay longer.

It is, of course, useless to lay down rules for successful management. A man's methods are born with him, and if an attempt were to be made to establish rules for success by consulting examples of success, the rules would cover all conceivable methods and be in hopeless conflict with one another. At the same time we believe it to be true that the most successful management is largely based upon the exception system. It is easy to find examples to the contrary, of eminently successful managers who are loaded down with work and who find it impossible to avoid attention to details which should be attended to by others, but successful management of this kind is achieved at the expense of tremendous effort. It would be too much to say that a manager following such methods has mistaken his calling, but it is not too much to say that he has failed to learn the secret of the highest success in his calling. While a manager of this type may be eminently successful, nevertheless limits are set to his success, since with the growth of his works in magnitude a time must come when the day contains too few hours for him to do the things which he sets out to do. As this growth goes on, if the manager is to continue to be equal to his task, he must learn to delegate work to others and to trust their judgment, and, whether the principle is formally recognized or not, he can, we believe, do it in no other way so successfully as by adopting the exception system. If what seems to many the great mystery of the successful management of the enormous works of today were analyzed, we believe that it would in most cases resolve itself into this very principle. A detailed knowledge of the work going through many of the immense establishments of today by any one man is impossible, and the manager who attempts it will sooner or later fail.

Co-operation Versus Duty

A great deal has been written and spoken in regard to cooperation in industrial life, that is, among the members of factory organizations. Is it not about time to put another face on this subject and speak of the duties of the members of a factory organization to themselves and to their employers? Coöperation carries with it the idea of combining together for a common end, while duty has the idea of doing that which is an obligation. Employees of any factory enter into an agreement to perform certain labor or duties in return for a certain recompense. Is it not better, therefore, to look upon a successfully operating manufacturing plant as one in which each member does his duty rather than as a condition in which each member coöperates with his neighbor? Is it not a higher principle of service to look at it from the standpoint of duty rather than from any other?

New Publications

THE "MECHANICAL WORLD" POCKET DIARY AND YEAR BOOK FOR 1908. 391 3¼x6-inch pages in all, 307 exclusive of advertising and 59 illustrations in the text. Price, sixpence net. Emmott & Co., Limited, Manchester, England.

This is the twenty-first year of the publication of this handbook. Compared with the publication of last year there are two important changes. The matter on electrical transmission has been omitted owing to the bringing out of a companion volume, the "Mechanical World" Electrical Pocket Book. New material on Condensers, Superheating, Reverberatory and Reheating Furnaces and Friction Clutches has been added. There are also several new tables dealing with standards for machine parts. The changes add to its value as an inexpensive mechanical handbook. The daily diary is, of course, a prominent feature.

THE "MECHANICAL WORLD" ELECTRICAL POCKET BOOK FOR 1908. 247 3¼x6-inch pages in all, 206 pages exclusive of advertising and 50 illustrations in the text. Price, sixpence net. Emmott & Co., Limited, Manchester, England.

This work has been suggested by the former success of its companion which is reviewed above. Like its companion it has a daily diary as one of the prominent features. It is elementary in its character and treats of problems in the mechanical side of electrical engineering. Quoting from the preface it is "specially intended for those in charge of electrical plant and machinery and for power users and others interested in the industrial application of electric power." There are several common yet useful tables, notes on the installation and care of wiring and electrical machinery, transmission of power by mechanical means, and the like. It hardly measures up to its name of an Electrical Pocket Book, yet it is a creditable compilation when one considers the selling price, 12 cents.

ENGINE-ROOM CHEMISTRY. By Augustus H. Gill; 198 4½x7-inch pages, with 46 illustrations. Price, $1. Hill Publishing Company, New York City.

The operating engineer is vitally concerned with the behavior of fuel, oil and water. This volume takes up the chemistry of these substances in a simple manner, indicates what apparatus is needed for and how to perform the necessary experiments and tests to gain a working knowledge of their qualities, properties and applications. The chapter headings are: Introductory; Apparatus and Chemicals; Fuels and Their Analysis; The Regulation of Combustion; Water, Boiler Scale, Pitting and Corrosion; Mineral Oils; and Animal and Vegetable Oils. An appendix has tables of data useful in connection with the tests and computations which are described. While such a work could not be written without using chemical symbols, yet they are explained in such a simple manner that a knowledge of chemistry is not necessary to understand them. Again, the apparatus which is described is of the simplest kind.

TABLES OF THE PROPERTIES OF STEAM AND OTHER VAPORS AND TEMPERATURE-ENTROPY TABLE. By Cecil H. Peabody. 131 6x9-inch pages. Price $1. John Wiley and Sons, New York City.

This is the seventh edition of this well known work rewritten in the light of recent important experimental investigations. The tables have been recomputed and certain changes introduced to facilitate their use.

To aid in the solution of adiabatic problems, to which prominence has been given by the development of the steam turbine, a Temperature-Entropy Table has been constructed for saturated and superheated steam. Quoting from the preface: "For engineering purposes the answers for such problems [adiabatic problems] may be read directly from the table; greater refinement can be had by interpolation when that is thought desirable." This table is a valuable addition to a previously most valuable work. We cannot fail to recognize, although we cannot perhaps appreciate, the enormous amount of detail labor necessary to determine the quantities entering into these.

New Tools and Machine Shop Appliances

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THE LATEST INFORMATION

A Press Operating Two Dies Simultaneously

To accomplish rapidity of manufacture and the consequent reduction in the cost of production operations wherever possible, in the manufacture of sheet-metal goods are often combined. With this idea in view, the press shown in Fig. 1 was built for producing at each stroke a blank such as shown in Fig. 2, which blank requires two operations. The operation of the press is simple. The first die *A* is a regular combination die; it cuts, draws and forms the blank. The press being in an inclined position the formed blank then falls by gravity down a chute and stops at the finger gage *B*, which, in conjunction with the chute, holds the blank in position until the next revolution of the press at which time the wiring is done in the wiring die *C*. At the same time, another blank is also being cut and formed in the combination die. On the next stroke the wired blank is released by the operation of the finger feed at the back of press, and falls into a receptacle placed to receive the finished blanks. The finger feed returning quickly centers the next blank to be wired, repeating the operation at each stroke of the press. The feed is operated by a cam *D* on the end of the crank-shaft. The crank-shaft has a stroke of 2 inches. The mandrel is fitted with a cross-bar knockout. The fly-wheel weighs 950 pounds and makes 125 revolutions per minute.

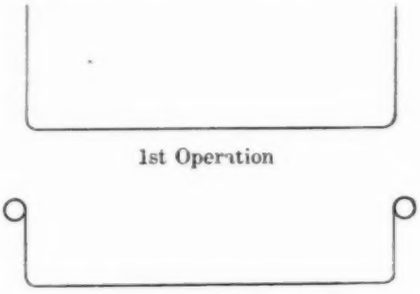


FIG. 2. THE WORK

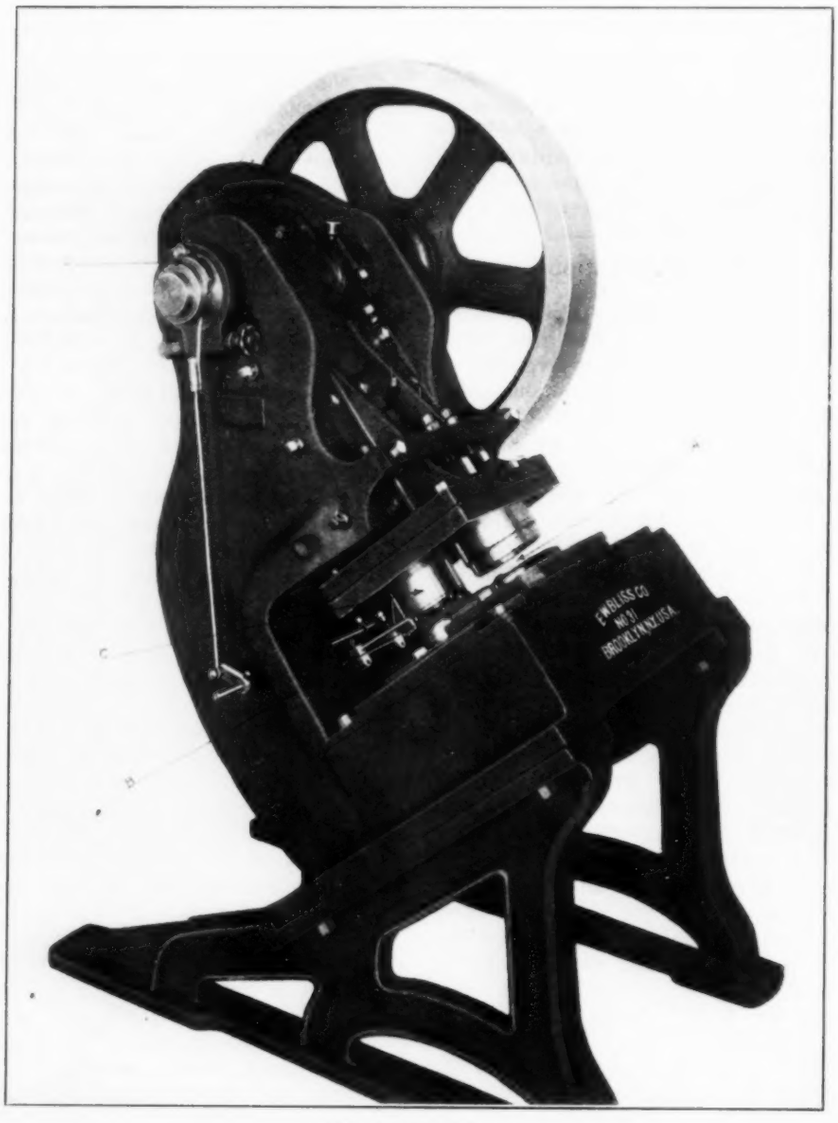


FIG. 1. THE PRESS

The press as shown weighs 5350 pounds, and is made by the E. W. Bliss Company, 1 Adams street, Brooklyn, N. Y.

A Horizontal Drilling, Boring and Milling Machine

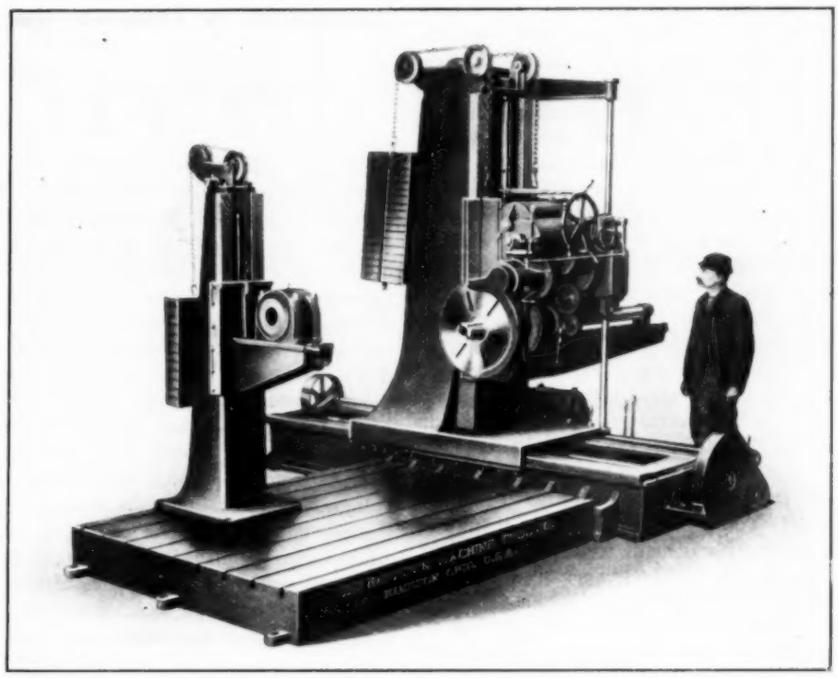
The half-tone shows a machine designed for performing drilling, boring, tapping and milling operations on large or unwieldy pieces which are difficult or inconvenient to move.

The work is secured to the floor plate which is provided with T-slots. The outboard support is also secured to the floor plate, or can be removed when not in use.

The main column is adjustable on its ways. The head is vertically adjustable on the column and is counterbalanced as is also the outboard support. Graduated scales are provided on both the main and outboard columns so that correct alinement is readily obtained. Hand and power feeds are provided for the column, head and spindle. The feeds for the column and head are eight in number from 0.0196 to 0.66 inch per revolution of the spindle. The spindle has also eight automatic feeds from 0.001 to 0.033 inch per revolution.

The machine is driven by a single pulley running at constant speed which by means of a speed box is converted into 16 gradations of speeds from 2 to 180 revolutions per minute. All the feeds are gear driven and can be changed without stopping the machine. All exposed gears are provided with guards.

The floor plate is 8 feet long, 6 feet wide and 10 inches thick. Traverse of column on the bed, 72 inches; vertical traverse of the head on the column,



A HORIZONTAL DRILLING, BORING AND MILLING MACHINE

40 inches; traverse of the spindle, 36 inches; minimum distance from the center of the spindle to the top of the floor plate, 24 inches; maximum distance, 64 inches. This machine weighs about 30,000 pounds and is built by the Hamilton Machine Tool Company, Hamilton, Ohio.

Westinghouse Direct-current Starting Rheostats

Direct-current motors, except in the smallest sizes, require some sort of starting device to keep the current within safe limits and to prevent the motor from starting with too great a rush. The necessity of using satisfactory starting devices is therefore as great as to have the motor itself reliable. The Westinghouse Electric and Manufacturing Company has developed a line of face-plate starters which fully meets the specifications and conditions laid down by the National Board of Fire Underwriters and the American Institute of Electrical Engineers.

The starters for motors on 110 volts up to 22 horse-power, or 220 volts up to 35 horse-power, use the bar type of resistance, which consists of a resistance wire wound on iron bars which are first covered with a fire-proof material. See Fig. 1. The ends of the bars are held in place by porcelain pieces, clearly shown in the acompanying illustrations. The construction is strong and rigid, so that adjacent turns on the same bar cannot short circuit, nor can turns on one bar come in contact with turns on another bar. The whole construction, resistance, iron frame, slate front, contact arm, etc., is fireproof.

Another feature embodied in these starters is the low voltage release. The contact arm will positively fly back to the off position if the current is shut off from the line, or if the voltage falls below a fixed limit. This prevents damage to the

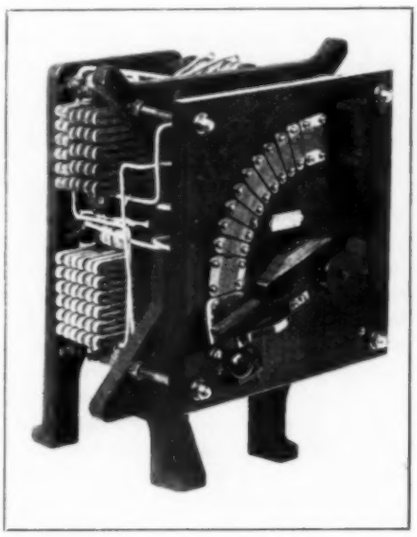
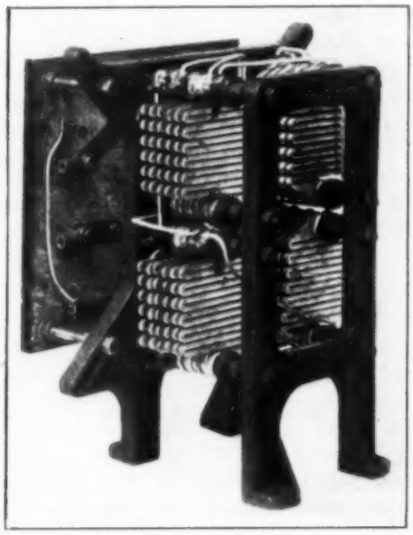


FIG. 4



GRID TYPE OF MOTOR STARTER, 240 AMPERES CAPACITY FIG. 5

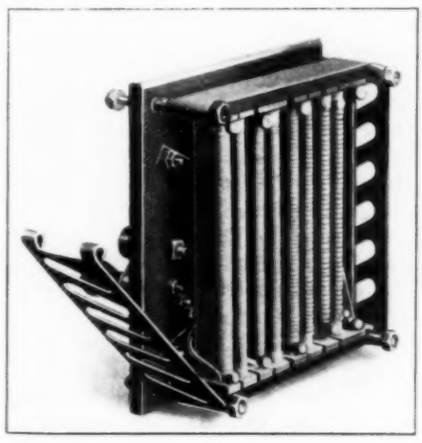


FIG. 1. BAR TYPE OF MOTOR RHEOSTAT

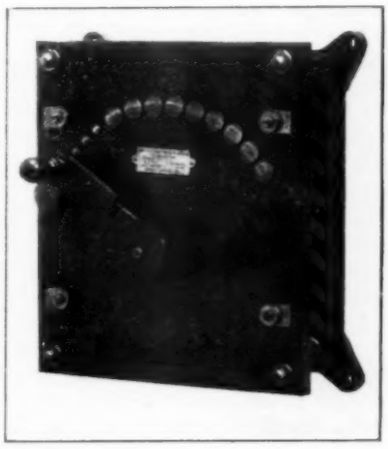


FIG. 2. FACE PLATE MOTOR STARTER, 80 AMPERES CAPACITY

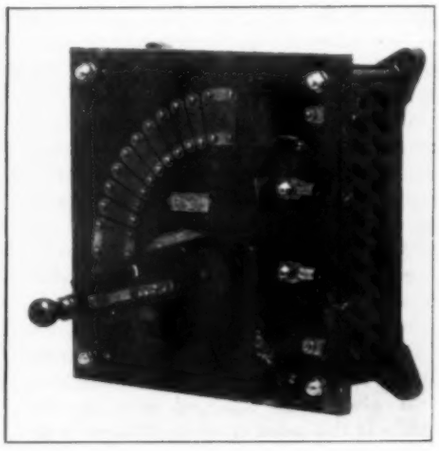


FIG. 3. FACE PLATE MOTOR STARTER, 160 AMPERES CAPACITY

motor should the current again be thrown on or the voltage rise suddenly to its full value. The method of connecting the magnet of the release coil will be found of special benefit where the field of the motor is to be regulated. The magnet is connected across the line independently of the shunt field and is unaffected by variations in the field current.

The small button type of rheostat shown in the illustration, Fig. 2, is used on the smaller types of motors and is capable of carrying 80 amperes. For the larger motors larger contacts are required; this requirement is met by furnishing renewable contacts, as shown in the illustration, Fig. 3, of the 160-ampere rheostat. In this larger type of starter a special short-circuiting brush is provided which cuts out the last contact, insuring the lowest possible resistance.

For starting motors on 110 volts of 25 horse-power, or 220 volts of 45 horse-power and larger, the grid type of resistance is used. This is fully ventilated and will stand the heavy duty required in starting large motors. All contacts, brushes, fingers and springs may be removed from the front with ease. See Figs. 4 and 5.

As these rheostats are used only in starting, the handle will not remain on any point except the last, unless held. They are intended to bring the motor up to speed in 15 to 30 seconds according to size, and are made for full load conditions. This line is fully described in leaflet No. 9000.

The Simple Lathe and the Turret Lathe

By C. W. Sutherland

On page 959, Volume 30, Part 2, there is an article entitled "A Plea for the Simple Lathe." Its author appears to be having a rough time among turret lathes. It is evident from the facts set forth that the turret lathes in his works are not being handled to the best advantage; in which case his plea for the simple lathe is justified.

We employ a number of turret and capstans lathes in our works on chucking and bar work, and they are giving every satisfaction. The saving effected by their use is very considerable. Of course, we don't have to wait a month for the tools to come from the tool room, otherwise we should drop money very fast. It is never advisable to use indifferent tools on a simple machine, much less on a turret lathe. To be efficient the latter machine must always be equipped with proper tools. If this point is ignored, there is no advantage to be gained.

Where the work to be done is suitable, and sufficient quantities can be put in hand at one time, it invariably pays to employ turret lathes. Our turret-lathe department is growing and we are discarding engine lathes. Of course we have some jobs that do not call for turret lathes at all, and for these we content ourselves with the ordinary engine lathe.

Mr. Sparks tells us something about a demonstrator. "A machine is purchased," he says, "and set up. The demonstrator arrives and puts a job in the chuck, but finds that a special set of jaws would be better; later he also finds that a special tool would be better. To make the necessary tools four toolmakers, a tool dresser and his helper are working at high pressure." Wonderful forethought! This done, the demonstrator makes a start on the job in question and proves the turret lathe a "wonder-working machine." Alas! The demonstrator leaves them and some attempt is made to do a job on their own account. Nobody appears to take the initiative in designing and making suitable tools, therefore the machine gets but an indifferent trial and is denounced. All this, of course, is hard lines on the "smiling boss" and the firm who supplied the machine. The demonstrator doubtless did his best and was glad to get away on another job where better conditions existed. I think I am right in saying that a demonstrator instructs the customer's operator in the efficient handling of the machine, but, of course, with indifferent tools this cannot be done effectually.

A 4-inch diameter steel bevel wheel which has a clutch on its face and a long hub for its own shaft is mentioned. This job had been done on a turret lathe, but owing to a change in design the tools had to be scrapped. Of course, we all have to alter our designs, but the reason for scrapping the tools is hard to see, not knowing the alterations. It appears to be still a bevel wheel and possibly has a clutch on its face and a long hub for its own, shaft, as it was afterward done on a cutting-off machine and four engine lathes. The bevel wheel in question is a good job for the turret lathe. For this class of work standard boring-bar holders, combination tool holders, etc., should be used, as in most cases where the design is altered it is merely a question of new cutters.

In intelligent hands the turret lathe is without doubt a great labor and time saver and occupies a minimum amount of floor space. The latter point is a very important one. Where simple machines are employed the floor space required is considerable. We make bevel wheels similar to the one mentioned, and the cost of production is very low. In fact we could not afford to machine them on the ordinary lathe. If we were to use simple machines to the extent mentioned by Mr. Sparks, our shop would be so large that we would not be able to see from one end to the other for the curvature of the earth.

Inaccuracies in Technical Books

By P. R. Hough

Having collected an extensive library of technical works, and also a large line of catalogs covering branches of the industrial arts similar to those discussed in several volumes purchased as special authorities on these arts, I have arrived at the conclusion that there is altogether too much indiscriminate bookmaking in this country. As a fair example; in one volume written by a gentleman whose name is well known throughout the country I find tables and statements copied from a catalog antedating the volume, and containing the incorrect estimates and assumptions of the catalog, which were published originally to promote the interests of the manufacturer. Again, in this same book, there are errors in the first few pages which cause one to lose confidence at once in the entire work.

The above is cited as only one instance. The sooner common sense is used in building up a volume, and the use of catalog statements are checked up with calculations and experience, the more weight will be attributed to these volumes and the general arts and sciences will feel the impulse of development. The man who really knows his art is generally so busy that he has little opportunity to prepare a volume. This is unfortunate, but we might better be without these books than to be constantly misled by subject matter over the name of a prominent author which he has "cribbed" from unreliable sources.

The field of the gas engine has bred a lot of treatises during the past few years, most all of which are delusions pure and simple; the statements are erroneous and not at all in keeping with the development at the time of writing. For instance: One writer states that the flash-point of kerosene oil is 115 to 125 degrees Fahrenheit, demonstrating that he has never purchased a gallon of this oil in his life, or he would know that the State regulations for the commercial oil are invariably drawn to make 150 degrees the low limit for the flash-point, and that it is this oil which is on sale all over the country. A man is engaged perhaps in the business of building lathes and making little noise about it, when suddenly a volume comes out written by him on the subject of the "Influence of Sea Water on Concrete."

While there is no disposition on my part to depreciate the efforts of American authors, the spirit expressed herein will explain why we are obliged to translate works published abroad where the arts are treated with more care as a rule, and the works more authoritative.

Steel and Its Uses

BY EDMUND F. LAKE

Furnaces for Converting Iron into Steel

Bessemer Process; Acid Open-hearth; Basic Open-hearth; Crucible and Electric Furnaces and Comparative Quality of Steel Turned out

The iron which forms the base for all steel as well as iron products is first obtained, as a commercial product, from its ores in the form of "pig." This pig iron contains a large amount of carbon, both in the graphitic and combined state, which makes it too weak and brittle for most engineering purposes and it is used only for castings that are to be subjected to compression, or transverse and very slight tensile strains, such as bed plates or supporting parts for machinery, water pipes, stove plates, car wheels, etc.

The various kinds of steels are therefore relatively increasing in proportion to the amount of pig iron used. Today about two-thirds of this product is being turned into steel through purification by either the bessemer, open-hearth, puddling or crucible methods.

The carbon content is reduced to any desired point, the graphitic carbon is eliminated by any of these processes and the silicon and manganese are oxidized out by the accompanying reactions, or as a condition precedent to the reduction of the carbon.

The two impurities of the metal which are the greatest bane to engineers and steel makers alike are phosphorus and sulphur. These are reduced by either the basic open-hearth, puddling or crucible processes.

Melting the Ore

In making steel, the operation begins by making pig iron from the iron ore, which is a natural iron rust or a combination of iron and oxygen. The oxygen is removed by combining iron ore, coke and limestone in a furnace and heating them to a high temperature by injecting superheated air into the bottom of the furnace.

The coke is burned by the oxygen in the air; a part of it aids in maintaining this high temperature while the rest is useful in removing the oxygen from the ore.

This superheated air is usually heated with the gases which have been conducted from the top of the furnace to the bottom and passed through a stove. The stove in turn is heated by burning some of the gases from the top of the furnace. The limestone unites with the earthy materials as the ore is being reduced to a molten state and is run off from the top of the iron through a hole in the side

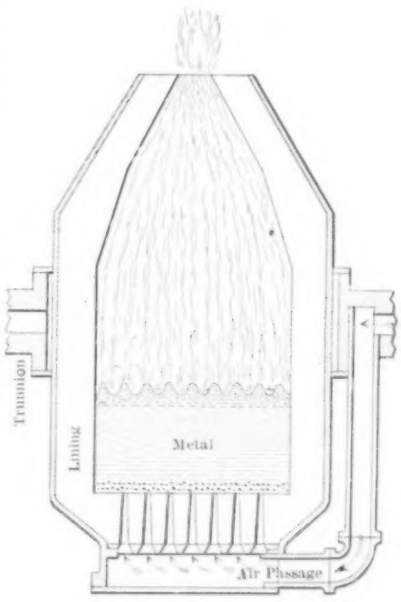


FIG. 1. BESSEMER CONVERTER

of the furnace. The metallic iron melts and collects in the hearth below the tuyeres and is tapped out of another hole close to the bottom from which it is run through channels into molds that form it into "pigs." The channels are called "sows."

While the metal is in contact with the white-hot coke in the furnace it absorbs a certain amount of carbon, some of which is chemically combined with the iron and another part is held in suspension as graphite.

If the "sow" and "pigs" are cooled slowly it tends to make the carbon take the form of graphite. When such iron is broken it has a gray or black appearance showing loose scales of graphite and the iron is soft and tough.

If the metal is cooled quickly, or chilled as soon as it comes from the furnace, the carbon has a tendency to be kept in the combined state. When fractured such metal will be white and hard.

Use of the Product

Of this product about 20 per cent. is made into gray-iron castings, 3 per cent. into malleable-iron castings, 3 per cent. is purified in puddling furnaces to make wrought iron and the balance or 74 per cent. is converted into steel by the various processes; of which 52 per cent. is converted by the bessemer process, 19 per cent. in the basic open-hearth furnace, 4 per cent. in the acid open-hearth furnace and 1 per cent. by the crucible process.

Bessemer Process

The bessemer process consists of a converter similar to that shown in Fig. 1, which is pear shaped and open at the small end. It is hung on trunnions so the metal can be easily poured in and out of it. Into this is poured the melted pig iron, which is usually taken direct from the furnace although it is sometimes remelted, and through this is blown cold air in fine sprays in the proportions of about 25,000 cubic feet of cold air per minute to every 10 tons of molten metal.

Curious as this may seem to the uninitiated, the cold air raises the temperature of the molten metal to such a high degree that it is often necessary to inject steam or add scrap to cool off the metal. This rise in temperature is due principally to the silicon in the iron which comes in contact with the oxygen of the air and produces a state of combustion which oxidizes out the silicon and manganese in about four minutes, after which the carbon begins to oxidize to carbon monoxide, CO, which boils up through the metal and is forced out of the mouth of the converter in a long bright flame which gradually diminishes, until at the end of six minutes more the carbon has been reduced to about 0.04 per cent. and the flame dies away.

Adding Alloys

Except for the impurities which poison the metal, namely phosphorus and sulphur, it has become for all practical purposes a pure metal which is very brittle. It is now necessary to add certain ingredients which toughen, strengthen and harden it to make it useful and workable.

Carbon is added in different percentages while it is in the molten state to give it the proper degree of hardness.

Manganese is added for the purpose of reducing the sulphur and oxygen which the metal has absorbed during the process of conversion, as the oxygen would render it unfit for use and the sulphur if present in too large a percentage would make the metal "hot short," which would make it difficult to roll or forge when heated.

The manganese desulphurizes the molten metal by causing a gradual liquification of manganese sulphide which rises to the surface allowing the sulphur to oxidize into the air.

Silicon is also added for the purpose of freeing the metal from blow-holes by reducing the gases which work to the top under the influence of the chemical action caused by silicon.

Of the last two elements but from one-half to two-thirds of the percentages added will be found in the finished product owing to their combining with the impurities and oxidizing out with them.

In the bessemer process it is almost impossible to reduce the phosphorus and especially is this so with the acid bessemer process which is the one used in this country. The percentage of phosphorus which goes into the furnace in the ore and coke will come out in the finished product after it has passed through the converter; hence, it is necessary to use ores and coke which are low in phosphorus if a good steel is to be produced.

In Europe, however, the basic bessemer converter is used to a certain extent. This is the same as the acid except that the lining of the furnace is of some basic material such as limestone, containing from 30 to 40 per cent. of magnesia and burned hard, commonly called dolomite.

The chemical action of this causes the phosphorus to slag off but ores which are low in silicon must be used.

The bessemer process being the cheapest way of converting iron into steel all of the cheaper and ordinary grades of steel are made by it.

Open-hearth Process

The open-hearth furnace as the name implies has an open hearth on which the metal is placed and there it is exposed to a flame which reduces it to a molten state; or, in other words, it is openly exposed to the action of burning gases.

This furnace must be a regenerative one to get the high temperature which is needed to melt and boil the metal. By this is meant one in which the heat carried away by the chimney flue is used to warm the air and gas before they enter the furnace.

This name has been commonly applied to the furnace as shown by the sectional view in Fig. 2, by which both the air and gas are heated before entering the furnace by sending them through passages filled with bricks which are stacked up so as to leave openings between them.

Two sets of passages are provided so that one can be used to absorb the heat in the exhaust gases while the other is warming the incoming air and gas. These passages are supplied with reversing valves so that they can be used alternately and thus heat the gas and air to a yellow heat before they unite. This method gives a very intense heat.

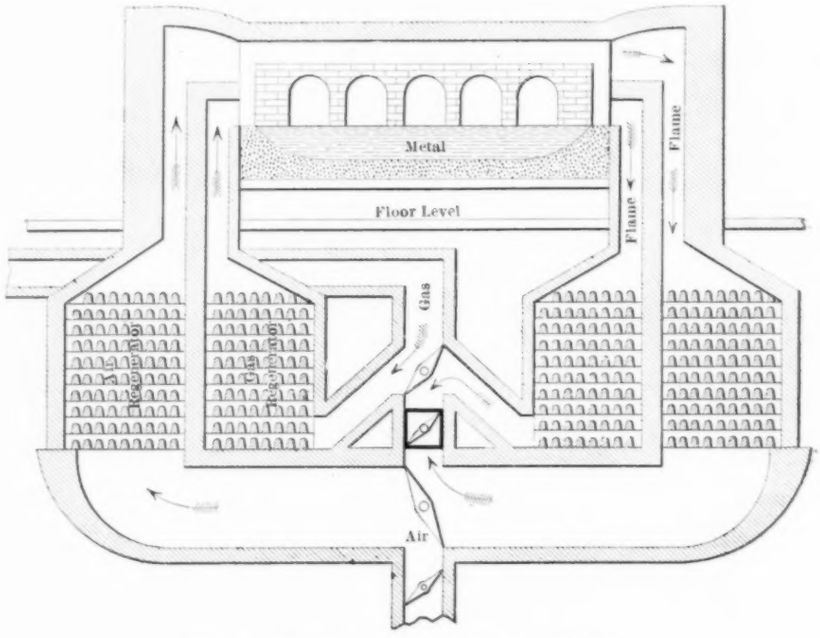


FIG. 2. REGENERATIVE OPEN-HEARTH FURNACE

In the open-hearth furnace pig iron is mixed and melted, with wrought iron, steel or similar iron products, in such a manner that the final product is entirely fluid; thus converting the resultant bath into steel.

From 30 to 75 tons of metal are purified in one of these furnaces in from 6 to 10 hours. It is then "recarbonized," or in other words the proper percentage of carbon is added, and the metal poured into ingot molds from which it is taken and rolled or forged into the sizes and shapes desired.

Steel is made in two ways with the regenerative open-hearth furnace; one is called the acid open-hearth process and the other the basic open-hearth process.

Acid Open-hearth

In this process the metal lies in a pool on the long hearth the same as in the basic as shown in Fig. 2, but the lining of the hearth differs in the materials used.

The furnace is lined with silicous materials (sand) for the acid process. This lining influences the subsequent operations as the character of the bottom determines the character of the slag that can be carried, which, in turn, determines the chemistry of the process. The metal is heated by radiation from the high temperature of the flame. The impurities are oxidized by an excess of oxygen over that which is necessary to burn the gas in the furnace. This oxidizes the slag which, in turn, oxidizes the impurities in the metal.

The slag is about one-half silica (SiO_2) and the other half is composed of oxides of iron and manganese. Nothing is added to form a slag as the combustion of the silicon and manganese with what iron is oxidized and some sand from the lining in the bottom gives the necessary supply.

When the metal is melted iron ore is added, the oxygen in the ore oxidizes the excess of carbon until the proper percentage is acquired, the furnace is tapped and the proper percentage of manganese is thrown into the ladle at the time of tapping. This is in the form of a rich ferro-manganese and not in the form of a melted spiegel iron as is the general practice in the bessemer process.

In this process the percentage of phosphorus and sulphur depends upon that in the stock which is put in the furnace, but the amount of carbon in the steel and, therefore, its tensile strength depends entirely on the conduct of the operation.

Most engineers and machinery designers agree that acid open-hearth of a

given composition is more reliable, less liable to break and more uniform than either bessemer or basic open-hearth steel.

It is usually easy to tell the difference between basic and acid steel, but it is difficult to tell the difference between basic bessemer and basic open-hearth steel or between acid bessemer and acid open-hearth steel. Therefore, one has to depend on the honesty of the steelmakers unless they wish to go into exhaustive tests of each piece of steel received.

Basic Open-hearth

A regenerative open-hearth furnace, similar to that shown in Fig. 2, for the acid process is used for the basic, but the lining is of a different material. It is composed of some basic metal which is usually either magnesite or burned dolomite.

As the lining or bottom of the furnace takes little part in the operation, but determines the character of the slag which can be carried, when the bottom is silica (sand) the slag must be silicious and when the bottom is basic the slag must be basic. Therefore the charge put in the basic open-hearth furnace is composed of pig iron mixed with wrought iron, steel scrap or similar iron products, the same as in the acid furnace. But in addition to this lime or limestone is added, as the silica and the oxides of iron and manganese do not make a slag by themselves and, therefore, must have lime to unite with which gives a basic slag.

This slag will dissolve all the phosphorus that is oxidized which an acid slag will not do. In the acid open-hearth or bessemer furnace the silicious slag rejects the phosphorus which immediately deoxidizes and returns to the iron.

Sulphur is also removed to a limited extent and ore with these impurities can be used in the basic open-hearth furnace which is not possible to handle by the acid process.

If the slag is basic enough to not attack the bottom it will hold the phosphorus providing the stock does not contain over one-half of one per cent. With a higher percentage special attention must be given to the phosphorus to prevent its passing back into the steel when a high temperature is combined with violent agitation, as it is usual when the heat is tapped.

A basic slag will dissolve silicon and, although the phosphorus and sulphur are lower in the basic steel, the acid steel is considered better owing to the increased liability of "blow-holes" and gas bubbles in steel converted by the basic process, if the silicon is too low. Then again the process of recarburizing sometimes produces irregularities. The metal is also more highly charged with oxygen. All of these make a poorer quality of steel than is produced by the acid open-hearth process.

Crucible Steel

In the crucible process a regenerative furnace is used similar to the one shown in Fig. 3. In this the heat does not attack the top of the metal as in the open-hearth, but heats crucibles which are covered so that the gases from the fuel will not attack the metal. In some places, however, coke furnaces or melting holes containing crucibles are used.

The material used for conversion into steel by the crucible process is usually wrought iron and not pig iron as in the bessemer and open-hearth processes.

The wrought iron is cut up into small pieces and the desired amount of carbon is placed on top of it with any other alloying element desired such as tungsten, chromium, manganese, etc.

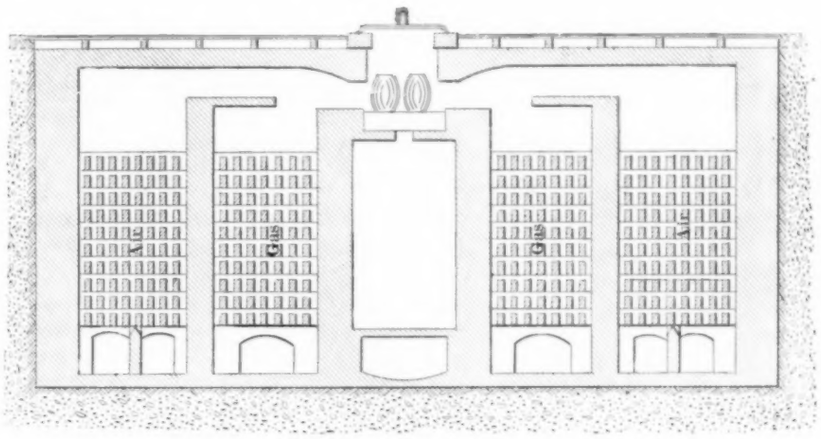


FIG. 3. REGENERATIVE GAS FURNACE FOR CRUCIBLES

In addition to these a little charcoal and a small amount of glass or other similar material is used to give a passive slag. In the pot are also a little air, some slag and oxide of iron, this last being the scale and rust on the surface of each piece of metal, and silica, alumina and carbon from the scorification of the walls of the crucible.

Some time is required for the reduction of the silicon from the slag and lining as well as for the various reactions which occur. When this reduction has reached a point where the steel contains from 0.20 to 0.40 per cent. of silicon and the metal lies quiet and "dead" the crucible is taken from the furnace and the contents poured into ingot molds.

The crucible process is used only for the making of high-grade and special alloyed steels, such as high-speed, nickel or vanadium chrome, etc. It is about three times as expensive as the next cheapest, namely, acid open hearth, but for such work as cutting tools, armor piercing projectiles, gears which are subjected to heavy or vibrational strains, high-grade springs and many other uses the crucible steels far excel anything that is made by the other processes.

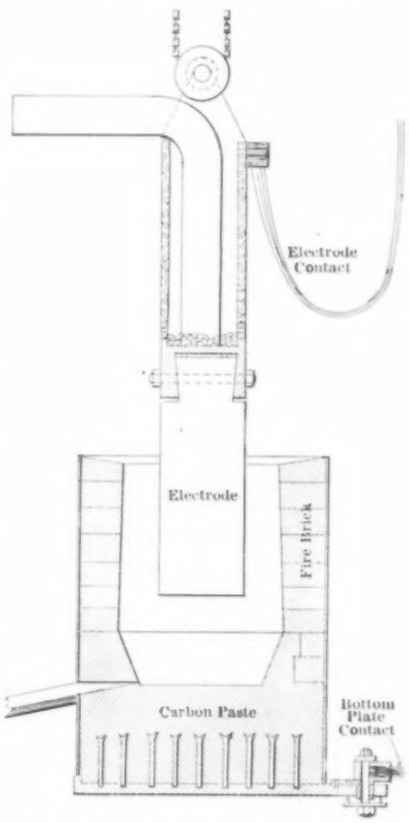


FIG. 4. DR. P. HEROULT'S ELECTRIC FURNACE

The reason for this superiority is largely due to the fact that it is made in covered pots, which exclude the furnace gases and air. It is therefore freer from oxygen, hydrogen and nitrogen.

Crucible steel usually contains less than 0.40 per cent. manganese, more than 0.20 per cent. silicon, less than 0.025 per cent. phosphorus and less than 0.030 per cent. sulphur, with the carbon content high owing to the uses to which crucible steels are put.

Electric Furnaces

The electric furnace has been brought into quite prominent use in the last few years for the making of steel. In certain

ways this has proved itself to be a commercial success, while in others it is still in the experimental stage.

Although there are many designs of electric furnaces they might be placed in two classes; namely, those in which the electrode enters the molten metal in the furnace as illustrated by the Heroult furnace in Fig. 4 and those in which the metal is melted by the radiation of heat from above the metal as illustrated by the Stassano furnace in Fig. 5.

The Heroult furnace is open at the top and the electrode is lowered into it. The current passes through the electrode, the metal in the furnace, the carbon paste lining and out at the bottom contact.

In the Stassano furnace the heat is generated by three electrodes which come together in the center of an inclosed furnace immediately over the metal. This furnace is also mechanically revolved in order to agitate the metal and thus accelerate the chemical reaction. It is also built without the revolving mechanism for some uses. Another prominent make is the Kjellin induction furnace.

When a good ore can be procured the electric furnace can produce a metal with a higher degree of purity than any of the other processes owing to the absence of the sulphuric gases. Mr. Harbord, the Canadian government expert said "Steel equal in all respects to the best high-grade Sheffield crucible steel can be produced in the electric furnace at a less cost than by the ordinary crucible methods."

The high temperature insures extreme deoxidization of the steel and a vigorous oxidization of the impurities can be employed in the electric furnace.

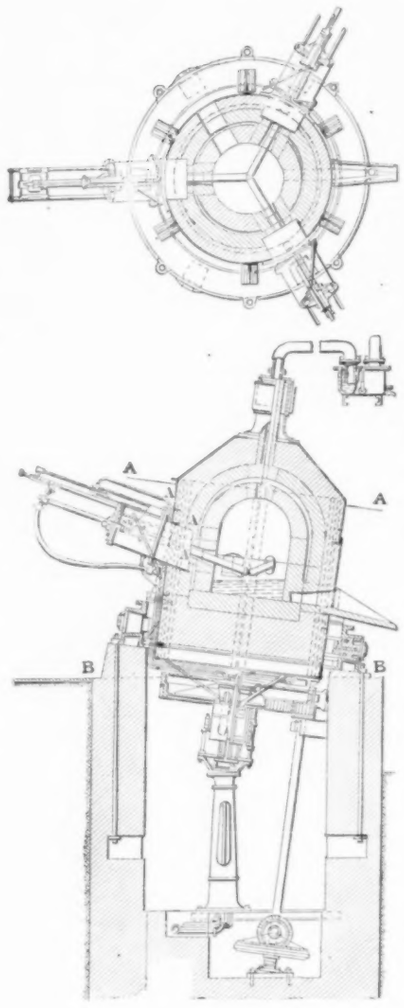


FIG. 5. REVOLVING THERMO-ELECTRIC FURNACE

It cannot eliminate arsenic and copper but it practically eliminates phosphorus and sulphur and thus removes the injurious effects of these. The sulphur is oxidized out until only a trace is left and the phosphorus remains in the metal only in very small percentages.

The electric furnace has not proved a success as yet for the making of steel from the ore, principally owing to the cost of production, but for the high-grade steels such as tungsten, nickel, nickel-chrome, self-hardening and high-speed tool, which are made out of blast furnace products and scrap it has given good satisfaction in Germany and France. But one of the electric furnaces has been tried in this country and that in the manufacture of a high-speed steel. After much costly experimenting this had to be abandoned owing to the lack of skilled labor to run it. The furnace itself was of the Heroult type which has given good results in other places.

A Sinding Larsen, of Christiania, Norway, has patented a process by which to obtain a merchantable iron, free from titanium and nitrogen, from titaniferous ore.

This ore is smelted in an electric furnace, and is then treated in a converter with nitrogen whereby titanium nitride and an iron containing some titanium are produced. This iron is then treated with superheated steam in order to decompose the titanium nitride, titanium nitride-carbide, iron nitride and possibly iron nitride-carbide. A pure iron is thus secured which can be treated by ordinary processes.

Ingredients of and Materials Used in Steel

Effects of These on the Static Strengths and Dynamic Qualities of Steel, Also on Its Workability and Wearing Qualities

The elements entering into the composition of steel have been studied and investigated in many ways, and their effects have been carefully noted. Many new alloying materials have also been brought into use in the past few years. They were made available by the high temperature obtained in the electric furnace, and they have been experimented with and their effects recorded.

These new alloying materials have given us steels which for strength, cutting qualities, wearing qualities and ability to withstand vibrational and torsional stresses attain a standard of excellence higher than would have been considered possible but a short time ago.

Carbon in Steel

Of all the alloying elements entering into steel carbon is the most important, as it is the quantity and condition of the carbon in the metal which makes the distinction between iron and steel. The distinctive features of different grades of steel are due more to the variation of the carbon content than to the differences in the other elements.

One of the wonders of metallurgy is the effect that a small percentage of carbon has upon iron. Pure iron has a tensile strength of 5400 pounds per square inch, and if we add a few tenths of one per cent. of carbon, the tensile strength immediately rises to 60,000 pounds per square inch or more. This is a quantity so small that it is out of all proportion to the mass in which it is distributed.

Manganese, silicon, phosphorus, sulphur, etc., may vary widely in quantity but the carbon usually decides the class in which the steel belongs; for the carbon gives greater hardness and strength to the steel with less brittleness than any other element.

The carbon content of steel usually varies between 0.10 per cent. and 2 per cent. Metal having more than 2 per cent. is called cast iron and used as such. With a carbon content of from 0.10 to 0.30 per cent. the steel is soft and cannot be hardened enough to prevent cutting with a file. It is then called machinery, soft or low-carbon steel. With a carbon content of from 0.30 to 2 per cent. it can be hardened so as to cut other steels or metals and is called tool, half-hard, hard or high-carbon steel.

Exceptions to the above statement may

be made in hard steel, as a low-carbon steel can be made hard by either manganese, tungsten or chromium; but it is true of soft steel.

Every increase in the percentage of carbon increases the hardness and brittleness and therefore its liability to fracture when cold or when heated suddenly, while it reduces the elongation and reduction of area.

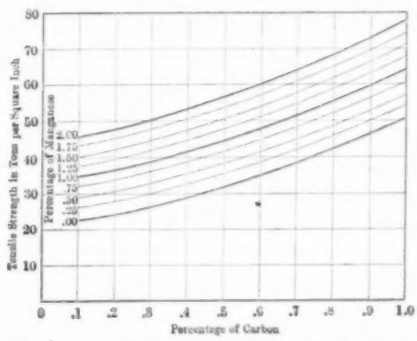


CHART 1. EFFECT OF MANGANESE BELOW 2 PER CENT.

The strength of steel is always secured at the sacrifice of some other desirable property, but the sacrifice is less in the case of carbon than with any other element. The tensile strength and elastic limit are raised considerably by hardening, and the higher the percentage of carbon the greater the degree of hardness which can be attained. But the greater the carbon content the less will be the elongation, as hardened high-carbon steel is very brittle. This brittleness makes high-carbon steel very easily damaged in heat treating or working, and the carbon content is usually kept as low as possible for the strength and hardness that is desired. "Sudden rupture" is a term which is especially applicable as a characteristic of carbon-steel products.

Many other elements which enter into the composition of steel, particularly in the special alloys, increase the strength and hardness of the metal as well as adding other desirable properties.

Manganese

Manganese is an element that is always found in steels but its true properties and effects on steel were not known until about twenty years ago, when they were discovered by R. A. Hatfield, a metallurgist and steelmaker of Sheffield, England. Its effect when added to steel up to 2 per cent., with various percentages of carbon, is best shown by Chart 1, the actual mode of existence of the carbon in the steel being very important.

When more than 2 per cent. and less than 6 per cent. of manganese is added, with the carbon less than 0.5 per cent., it makes steel very brittle, so that it can be powdered under a hand hammer. From 6 per cent. of manganese up, this brittleness gradually disappears until 12 per cent. is reached, when the former strength returns and reaches its maximum at about 14 per cent. After this, a decrease in toughness, but not in transverse strength, takes place until 20 per cent. is reached, after which a rapid decrease again takes place.

Chart 2 shows the effect of manganese, above 6 per cent. on the tensile strength and elongation.

Steel with from 12 per cent. to 15 per cent. of manganese and less than 0.5 per cent. of carbon is very hard and cannot be machined or drilled in the ordinary way; yet it is so tough that it can be twisted and bent into peculiar shapes without breaking.

Manganese in the form of a ferro containing about 80 per cent. of manganese is added to a heat of steel at the time of tapping so that it may seize the oxygen, which is dissolved in the bath, and transfer it to the slag as oxide of manganese. Manganese prevents the coarse crystallization which the impurities would otherwise induce and steels low in phosphorus and sulphur require less manganese than those having comparatively high percentages.

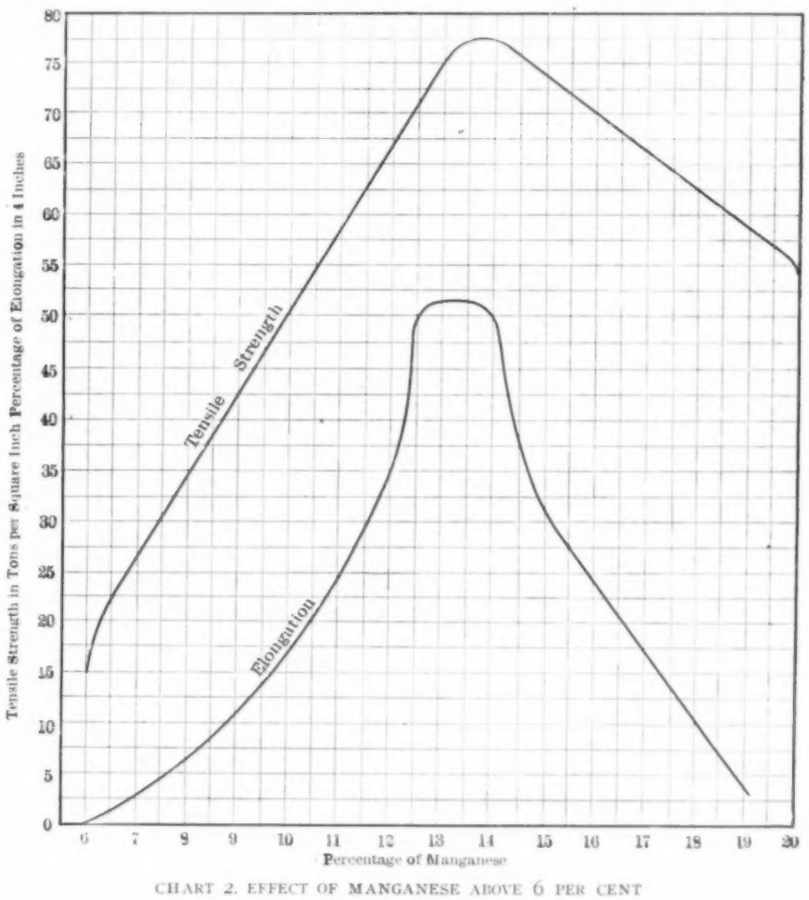

Tensile Strength in Tons per Square Inch Percentage of Elongation in 4 Inches
Tensile Strength
Elongation
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Percentage of Manganese

CHART 2. EFFECT OF MANGANESE ABOVE 6 PER CENT

The critical temperature to which it is safe to heat steel is raised by manganese, owing to its resisting the separation of the crystals in cooling from a liquid and conferring the quality of hot ductility. This makes it one of the most valuable factors in the making of steel, if the proper percentages are used. In the ordinary steels this percentage is usually from 0.70 to 1 per cent., while in many of the special alloys it runs from 0.30 to 0.50 per cent. In the high-speed steels the maganese content is from 0.10 to 0.30 per cent. and in case-hardening steels this should be kept below 0.20 per cent. The ductility which it gives to steel, especially when added in the percentages above the zone of brittleness, is decidedly affected by the rate of cooling. In this it works in the opposite way to carbon; slow cooling makes manganese steel brittle while quick cooling makes it extremely ductile.

Phosphorus

The impurities phosphorus and sulphur have been the bane of engineers, designers and all users of steel products and more time, more energy and more money have been spent to get rid of these than any other element in the metal. Many experiments have been carried on which proved that phosphorus up to about 0.12 per cent. strengthened steel, but when these same steels were put into actual use failures occurred and the cause was nearly always traceable to the phosphorus. In the rolling mill phosphorus does not show any bad effects as the heat under which the steel is worked seems to overcome them, but when the metal has become cooled

and is subjected to sudden shock or to vibrational stresses it breaks very easily. The lower the temperature and the higher the phosphorus the easier will the breaks occur. This has led to the term "cold shortness" as applied to the effect of phosphorus on steel.

Phosphorus diminishes the ductility of steel under a gradually applied load, as shown by the reduction of area, elongation and elastic ratio when specimens are pulled apart in the ordinary static strength testing machine. But when the steel is tested in the rotary or alternating vibrational-stressing machine, as well as with a pendulum-impact machine, the decrease in ductility and toughness is shown to a much greater degree.

Phosphorus steels are so capricious that they may show a reasonably high static ductility, and still show very brittle when shock tests are applied. Therefore, the safest rule to apply is to have the phosphorus in all steel products as low as possible. It is a bad steel that contains 0.10 per cent. of phosphorus, while the ordinary grades contain as much as 0.08 per cent., and the high-grade steels should have less than 0.04 per cent., while in the best steels it should be even lower than this.

Sulphur

Sulphur causes steel to crack, tear and check in rolling, forging, heat-treating or hot-working and, therefore, the term of "hot shortness" has been applied to its effect on steel. This is the opposite of the phosphorus effect. Its effect on the properties of steel when cold have not been accurately determined, but it seems certain that the effect is not detrimental to any extent.

When steel is heated beyond a dull red sulphur will cause a crystallization to take place, and when high temperatures are reached the grain becomes very coarse, as the sulphur is dissociated and forms into a gas which diffuses between the iron crystals separating them and preventing perfect cohesion. When contraction by cooling takes place this may cause microscopic cracks or even cracks large enough to be seen by the naked eye. These, of course, weaken the metal. It is also the bane of the steelmaker owing to its liability to cause blow holes, pipes and seams.

Sulphur also has an effect on the carbon owing to its tendency to form iron carbide and thus harden the metal. Its effect on the tensile strength of steel has not been definitely settled, but up to 0.10 per cent. it does not alter the elastic ratio, elongation or reduction of area to any extent.

The actual percentage of sulphur at which steel ceases to be malleable or weldable varies with the other ingredients. Each increment of copper lowers it, while each unit of manganese raises it; again, it is lowered if the steel ingots are cast too hot. The highest percentage of sulphur which should be allowed for any use is 0.10 per cent., but for tool making or other uses where steel has to be repeatedly heated and cooled this should not be over 0.03 per cent. and preferably as much lower as possible. Steel would be much better for nearly all kinds of work if the sulphur could be reduced to a trace and the improvements in electric furnaces give promise of doing this.

Silicon

Many contradictory statements have been made as to the effect of silicon on steel. When the silicon is left in the pig iron from the blast furnace it is an indication that the metal has been blown too hot, and as the iron has not been completely converted into steel the metal has a brittle character. The percentage varies considerably according to the heat of the charge and this causes irregularities which may account for the differences of opinion. To get the best results in the steel the silicon should be eliminated as much as possible from the iron, and a definite quantity added in the form of high percentage ferro-silicon or silico-speigel. This gives a very different effect from that of silicon left in the blast-furnace iron.

Silicon has a tendency to remove the gases and oxide from steel as well as the traces of dissolved oxygen. This prevents the formation of blow holes and makes the steel harder and tougher. Thus it is better able to withstand wear or crushing from continual pounding.

The influence of silicon on the results of quenching is similar to that of carbon in many ways. It is also dependent upon the coexisting amount of carbon and manganese. It neutralizes the injurious tendencies of manganese and it is difficult to obtain silicon in steel without the presence of manganese.

An increase in the percentage of silicon raises the tensile strength and lowers the elongation and reduction of area. Up to a content of 4 per cent., silicon increases the tensile strength about 80 pounds per square inch for every 0.01 per cent. Beyond this amount a weakening of the metal seems to take place. Without a considerable percentage of manganese silicon steels show very low shock resistance, whether annealed or quenched. With 0.20 per cent. of silicon the tensile strength is increased about one-third more than 0.01 per cent. of carbon would increase it. Beyond a content of 5 per cent. silicon steels are of but little use for structural purposes.

Steels containing a little less than 1 per cent. of carbon and from 1 to 2 per cent. of silicon have been used quite successfully for hard-tool steels. Below a content of 1 per cent., silicon ceases to have an influence on quenching and the metal may be classed as a special carbon steel. Some makers of steel try to keep the silicon as low as possible, but many of the best steels contain from 0.20 to 0.80 per cent. With the carbon content low the silicon may be raised to a fairly high figure, but with the carbon high the silicon should be kept low. It should also be kept low when the phosphorus is high.

Silicon steels are extremely fibrous with a remarkable resistance to shock in the direction of lamination but practically no resistance in a direction perpendicular thereto. This quality makes them specially adapted for leaf springs.

Effects of Copper

The iron made from some ores contains as high as 1 per cent. of copper and many of the bessemer and open-hearth steels contain from 0.30 to 0.50 per cent. of this metal. That copper associates with steel in perfect uniformity and does not segregate is a fairly well established fact. Hard and soft steels with a percentage of copper as one of the ingredients have been used for many purposes with the usual number of failures, but these failures have always been traced to other ingredients and none to the copper content. When the carbon content is high and the copper is from 0.45 to 2 per cent., the steel does not give good results when drawn into wire, but in the ordinary rolled shapes copper does not seem to affect the rolling qualities although the steel is not as readily weldable.

As much as 7 per cent. can be alloyed with iron but it makes a metal which is very hard to cut even with good tools. It slightly increases the elastic ratio and gives a better elongation and reduction of area. This would indicate that it is not harmful to steel and might be of a slight benefit.

Crank-shafts for the United States battleships and gun tubes for six-inch guns have been made out of steel containing 0.57 per cent. copper. They stood successfully all of the tests required by the Government.

Arsenic in Steel

Many steels contain an appreciable percentage of arsenic; but as high as 0.15 per cent. does not affect the mechanical properties as the elongation and reduction of area are not changed and the tenacity is but slightly increased, which leaves the bending properties unchanged at ordinary temperatures.

Above 0.15 per cent. the strength of steel is increased and the toughness decreased with each increase in the percentage of arsenic until 4 per cent. is reached, when the elongation and reduction of area become nill and the steel becomes very brittle.

Nickel

Nickel is one of the metals which is added to steel to increase its strength and wearing qualities and nickel steel is no doubt used more in the construction of machinery than any other of the special alloy steels. Nickel steel can be purchased in the open market in nearly all percentages of nickel from 1 up to 35 per cent. and with varying percentages of carbon.

Nickel segregates only slightly and

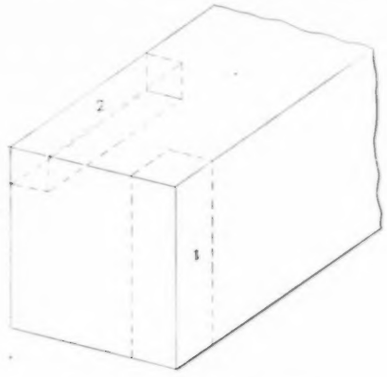


FIG. 6. CUTTING TEST BARS

gives steel a greater resistance to shocks, torsional stresses and compressive stresses, but this is not due to hardness as soft steel cannot be made hard by the addition of nickel.

The properties of nickel steel depend as much upon the carbon content as on the nickel. The fact that a 2 or 3.5 per cent. nickel steel is used means nothing unless the carbon content is right for the use to which the steel is to be put. To illustrate, a steel containing 2 per cent. nickel and 0.12 per cent. carbon has a good tensile strength with a great elongation and is useful for some purposes, while a steel that is equally useful for another purpose may contain 2 per cent. nickel and 0.9 per cent. carbon, and this would give it a high tensile strength with very little elongation. With a high carbon content nickel steel is difficult to harden, especially locally, as fissures and cracks tend to develop in quenching. It also has more tendency to warp in quenching than other steels and may be decarbonized by heating. These tendencies may be overcome to a great extent if the metal is thoroughly annealed before it is machined to size in order to relieve all of the internal strains. Then, when quenched the piece should be immersed in the bath so that the liquid can cover the greatest possible surface at the instant it strikes the bath and it should be agitated while cooling.

Nickel also gives steel a tendency to show laminations, and make it weaker at right angle to, than in line with the direction in which it is rolled. The higher the nickel content the greater will be the contrast between strength in these two directions. This is best shown by tests which were made on test bars 1 and 2 cut from a piece of 3.5 per cent. nickel steel as indicated in Fig. 6. Test bar 1 showed an elongation of 12 per cent. and a reduction of area of 17 per cent. Test bar 2 gave an elongation of 25 per cent. and a reduction of area of 65 per cent. The good qualities which nickel gives to steel offset these bad qualities to such an extent that it makes a much better steel for gears, crank-shafts and pieces which have similar work to perform than the ordinary carbon steel.

Nickel was first added to steel for the purpose of overcoming the property of "sudden rupture" which is inherent in all carbon steels. This it has done to a large extent. It makes steel better able to withstand severe shock and torsional stresses.

The tendency of steel to burn in heat-treating is greatly reduced by the addition of nickel and the extent to which its strength can be swayed by heat treatment is remarkable. One series of tests which were made showed a tensile strength of 88,000 pounds per square inch, an elastic limit of 60,000 pounds per square inch, an elongation of 28 per cent and a reduction of area of 58 per cent. when in the annealed state. These figures were changed by hardening to a tensile strength of 225,000 pounds, an elastic limit of 225,500 pounds, an elongation of 8 per cent. and a reduction of area of 19 per cent. A good quality of carbon steel might show these same figures in the annealed state, but they could not be raised to much more than half of those found in the nickel steel in its hardened condition.

Nickel has one peculiarity in its influence on steel which is best shown by Chart 3. Up to 8 per cent. it increases the tensile strength and elastic limit; from 8 to 15 per cent. it produces a steel so brittle that no mechanical tests are possible as the metal can be powdered with a hand hammer; at 15 per cent. the strengths are again restored and gradually reduce from that point on; from 20 to 25 per cent. the elongation rapidly increases, and from there on to 50 per cent. a gradual increase is shown.

Steel with percentages of nickel from 30 to 35 give good results for valves on internal-combustion engines as the nickel makes the steel wear better and it is not as good a conductor of heat as other metals.

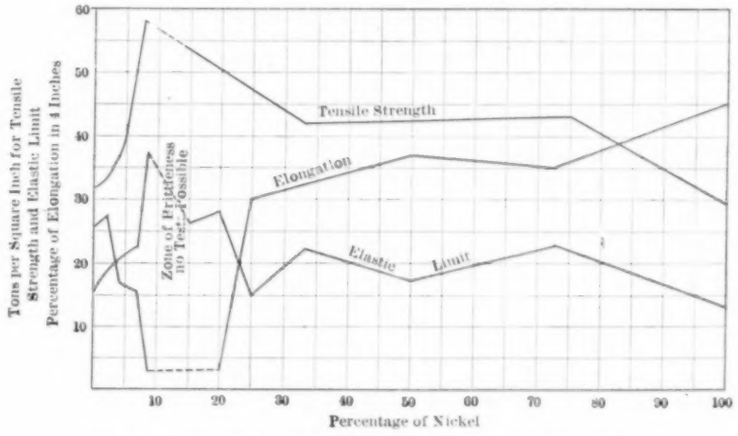


CHART 3. EFFECT OF NICKEL IN DIFFERENT PERCENTAGES

Tungsten

Tungsten as an ingredient of steel has been known and used for a long time, it having been used in the celebrated Damascus steel, but its actual effect was not known until about 35 years ago when Robert Mushet, after much experimenting, brought out the famous "mushet steel." This caused some radical changes in treating crucible steels and much progress and improvement has been made since that time.

Tungsten reacts on steel somewhat as does carbon, that is, it increases its hardness; but weight for weight carbon is superior in this regard to tungsten. If the percentage of tungsten is high with a proportionately high manganese content the steel can be hardened by cooling in the air. This is the direct opposite of the effect of carbon, and this fact Mr. Mushet used in his well known steel.

As the principal use of tungsten is in high-speed tool steel, and as a high percentage of manganese makes steel that is liable to fire crack, to be brittle, to be weak in the body and to be less easily forged and annealed, manganese at the present day is kept low and chromium is used in its place. The tungsten-chromium steels are not hardened by heating them to a degree of temperature that is unusual in tool steels, but they retain what hardness they have when heated to a dull red by the friction and pressure of chips in cutting. This has led to the term "red-hardness" as applied to this class of steel and it is this property which has increased the cutting speeds of tools. Tungsten when added to steel up to 7 per cent. does not make it any more self-hardening than the carbon tool steels if the manganese or

chromium are low; but every increase up to 19 per cent. increases the "red hardness" if chromium is increased proportionately. Beyond 19 per cent. of tungsten the "red hardness" is decreased no matter what the percentage of chromium may be. The increase in "red hardness" is about 50 per cent. with an increase in tungsten from 6 to 19 per cent. and that with manganese as low as 0.15 per cent. With the chromium in the proper percentage tungsten will make steel self-hardening in all percentages over 0.85 but if the chromium is too high proportionately the steel is liable to become injured by over-heating. By over-heating is meant heating considerably above the critical or recalescent point, which in the high-speed steels is about 1530 degrees Fahrenheit.

The carbon content of these steels is kept low as compared with ordinary tool steels, or the air-hardening steels of a few years ago; as the tungsten-chromium ingredients give steel a "red hardness." The carbon content in the high-speed steels of today usually varies between 0.65 and 0.80 per cent., whereas it was used in varying percentages up to 2.4 in the older air-hardening steels. This latter percentage was used in mushet steel.

The quality of "red hardness" given steel by the tungsten-chromium ingredients increased the cutting speed of tools about 45 per cent. over that of the older air-hardening steels, when cutting hard forgings or castings. Similarly an increase of about 90 per cent. was made when cutting softer metals. This has led to their almost universal use to the exclusion of mushet steel, which but a few years ago filled 50 per cent. of the sales of tool steel.

Tungsten either in combination with manganese or chromium has greatly lessened the skill and knowledge required in heat-treating tool steel. To get the proper degree of "red hardness" the steel should be heated nearly to its melting point. The melting point of steel is about 2500 degrees Fahrenheit. If this temperature was reached it would soften the steel so that the point of the tool would run. This would not harm the cutting qualities as it would not lessen the "red hardness" given the metal by the tungsten and chromium. If a greater temperature were reached it would melt the steel, so it can easily be seen when the melting temperature is reached. On the other hand, if a temperature of 2300 degrees Fahrenheit is reached the same "red hardness" will be given the steel, so that there is a range of about 200 degrees Fahrenheit that will give the same results in heat-treating.

The carbon tool steels, however, have to be heated to a few degrees above the recalescent point and then quenched to obtain the greatest degree of hardness. After this they must be drawn to remove the brittleness caused by the high temperature. This requires a great deal of skill to judge the correct temperatures, as a variation of 25 degrees will make quite a difference in the temper and consequently in the cutting and wearing qualities.

Molybdenum

Molybdenum is often used in high-speed steels in place of tungsten as its action is very similar. Where 2 per cent. of tungsten is used 1 per cent. of molybdenum will give the same results, that is, one molecule of molybdenum appears to have the same effect as one molecule of tungsten, its atomic weight being double that of tungsten. The cost of molybdenum is so much higher than that of tungsten that its use is prohibitive, unless much better results can be obtained.

Many experiments were made with molybdenum in place of tungsten, and molybdenum combined with tungsten, but these showed considerable irregularity in steels of the same chemical composition, heat-treated in the same way as the tungsten-chromium steels. The cause of these irregularities were not determined definitely, but the molybdenum tools seemed to run at their highest cutting speeds when heat-treated at a lower temperature than the tungsten steels. This would indicate that the heat-treating would require more skill in judging the temperature as it is very difficult to judge a definite temperature by the color of the steel after it has passed a yellow.

Molybdenum also has a tendency to make the steel more brittle and, therefore, weaker in the body as well as giving it a tendency to fire crack, which is a serious defect in tool steel.

Chromium

Chromium gives to steel a brittle hardness and refines the grain remarkably, owing to its tendency to prevent the development of the crystalline structure; but it gives no self-hardening properties although it is the element which in combination with tungsten produces the quality of "red-hardness."

Chromium added to steel in percentages up to five increases the tensile strength and elastic limit of hardened steel. In the annealed state the tensile strength is raised until 6.5 per cent. is reached and the elastic limit is raised up to 3 per cent. and this does not lower to any great extent until 9 per cent. is reached. After these percentages are passed a decided reduction takes place. This is best shown by Chart 4.

Extreme hardness may be obtained in chromium steels as the chromium intensifies the sensitiveness of the metal to quenching, and greatly reduces the liability of fracture which is found in carbon steels. With 2 per cent. of chromium steel is very difficult to cut cold; with higher percentages than this it is impossible to finish it with machine tools except by grinding.

Chromium steel practically shows no grain or fiber and possesses a high power of resistance to shocks. This has made it almost universally used for armor plate.

When chromium is combined with nickel or vanadium it makes the strongest and best wearing steel on the market and it can be machined and forged much more easily than when chromium alone is used. Small gears can be made with these alloying materials added to steel, that if properly heat-treated, will be so tough and strong as to make it almost impossible to break out a tooth, even with a sledge hammer. Some of the best grades of chrome-nickel or chrome-vanadium steel contain from 0.75 to 1.50 per cent. of chromium. If more than this is used the metal is too brittle and hard to keep the high strengths which are given by the lower percentages. The carbon content of these steels is also kept comparatively low. A percentage of 0.45 of carbon makes these steels about as hard as can be cut with machine tools, even when thoroughly annealed. Many of these steels contain only 0.25 per cent. of carbon as the chromium gives the metal a hardness similar to that given by carbon, but one which makes the cohesion of the molecules greater. This makes the metal much more homogeneous and gives it the ability to resist shock and torsional stresses. Thus, this alloy is one of the best steels for crank-shafts of internal combustion engines or other parts of ma-

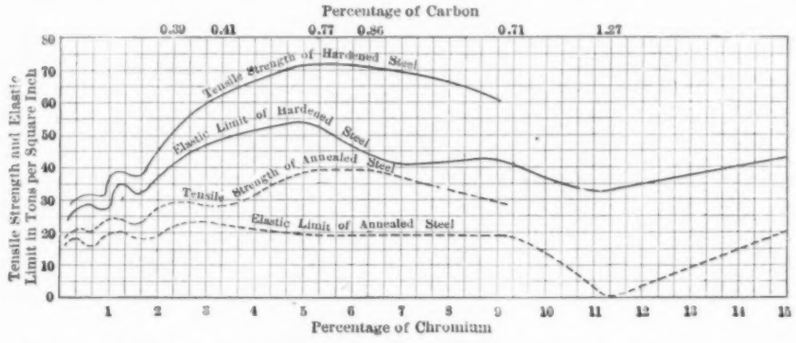


CHART 4. EFFECT OF CHROMIUM ON TENSILE STRENGTH AND ELASTIC LIMIT

chinery which have to withstand similar vibrational stresses.

The nickel-chrome steels are difficult to forge as it is dangerous to hammer them after the temperature has dropped below that which makes the metal a bright yellow. It must be heated many times to forge pieces of any size or of intricate shapes. The chrome-vanadium steels, however, are no more difficult to forge or machine than the 0.40 per cent. carbon steels. Chrome steels for armor plate are made with the chromium content about 2 per cent., while as high as 6 per cent. is used in some of the high-speed steels when the tungsten or molybdenum content is high.

Vanadium

Vanadium has made great strides in the past few years as an alloying element and is used in steel castings and cast iron as well as in steel mill products. In one respect it is similar to carbon in that very small percentages give the desired results. It is used in percentages varying from 0.16 to 0.18 for the moving parts of machinery and springs, while for case-hardening steel 0.12 per cent. is sufficient. In high-speed steels it has given good results in percentages of from 0.28 to 0.32. If used in too large a quantity it dynamically poisons the metal, and the dynamic qualities for which vanadium steels are noted are rendered no better than, if as good as the ordinary carbon steels.

Vanadium has the property of elusiveness to a marked degree. It has an affinity for oxygen and oxidizes out of the steel whenever it comes in contact with this element. Therefore, it has to be handled carefully by the steelmakers in order to keep it in the finished metal.

Vanadium contains within itself no virtues but it acts as a physic on other elements and is a powerful medicine. It gives the best results in the quarternary steels such as vanadium-chromium-manganese-carbon, vanadium-nickel-manganese-carbon and vanadium-tungsten-chromium-carbon.

Vanadium renders possible the natural formation of the sorbitic structure which makes the steel better able to withstand wear and erosion. It retards the segregation of the carbides, which renders steel susceptible of great improvements by heat-treating, and it gives to steel greater self-lubricating properties than any other element inherent in or alloyed with steel. Vanadium produces soundness mechanically as well as chemically and toughens the steel by acting as a physic on the other ingredients and increasing the molecular cohesion.

As all substances deteriorate in time, or, in other words, reach the end of their career and die we hear many terms applied to steel, such as "mysterious failure," "fatigue," "sudden rupture," etc., which in reality mean the end of the life of the molecules at the point of rupture. This is commonly called crystallization as the molecules cease to adhere to one another and form into microscopic crystals.

Vanadium seems to exercise a decided influence on these failures of steel by giving to the molecules a longer life. This makes the metal much better in its dynamic qualities, that is, resistance to repeated stresses, alternating stresses and simple repeated or alternating impacts, than can be made by any of the other elements. Vanadium also removes nitrogen which is very detrimental to steel even in infinitesimal quantities. It also toughens the constituent called pearlite and, when used in combination with chromium, reduces the brittle hardness given to steel by this element, so that it can be machined and forged as easily as an ordinary carbon steel.

While the cost of vanadium-chrome steel is from 6 to 10 cents per pound one firm, which builds gasolene engines, claims that it is no more expensive in actual practice than carbon steel, and is much cheaper than nickel steel, owing to the ease with which it is machined and forged, the lighter weight of the parts, owing to its great strength, and the greater accuracy obtainable, owing to the uniformity of the metal.

Vanadium steel is used largely for crank-shafts, connecting rods, piston rods, axles, crank-pins, gears, gun barrels, springs, locomotive side frames, etc.

Aluminum

Since aluminum has come into prominence in metallurgy it has found many uses and one of these is in the making of steel. This element, however, is only used as a purifier, as it adds nothing to the strength of steel except in so far as it removes some of the impurities.

Aluminum suppresses the evolution of gas either by increasing the metal's solvent power for that gas or by removing the oxygen and thus preventing the later formation, carbonic oxide, or by both means jointly. This greatly decreases the tendency of segregation as the aluminum has a quieting effect on the molten metal and the carbon, phosphorus and sulphur form compounds with the iron which are lighter than the molten metal and have a tendency to rise to the top. Only enough aluminum is used to cause this effect and thereafter work out of the metal. If solid alumina is produced it is liable to remain suspended in the metal and cause a lack of continuity of the metallic structure, and thus a loss of strength.

Chart 5 shows the effect of aluminum on the tensile strength, elastic limit and elongation of steel with various percentages of carbon.

Titanium

Titanium is another new element in the manufacture of steel. Its principal action seems to be on the nitrogen and oxygen. It has shown no effect as yet on the other elements. It combines with oxygen and hence has a tendency to remove it, but it is not as strong as some of the other elements in this respect. Its action on nitrogen far surpasses any of the other elements which have been experimented with. With this it forms titanium-nitride, which shows as tiny red crystals under the microscope. This nitride prevents the formation of blow holes and thus produces solid ingots, and the "pipe" is thus much smaller and flat.

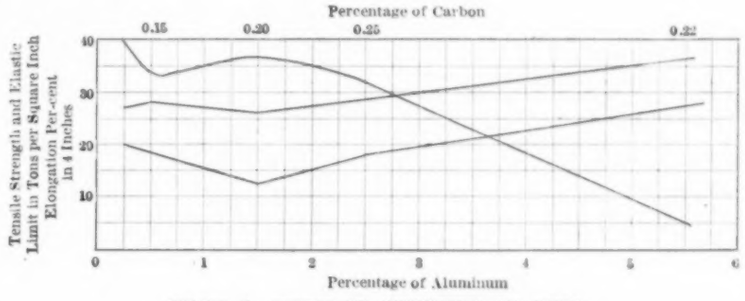


CHART 5. FEEFCT OF ALUMINUM ON STEEL

Due to this removal of oxygen and nitrogen the physical properties are improved and the density is increased. The tensile strength, transverse strength and resistance to shock are also much increased which may place titanium in competition with vanadium if future experiments improve on the good results already obtained.

Titanium increases the hardness, breaking strains and wearing qualities of the chill in cast-iron car wheels and similar products. It is said to greatly improve steel rails, so that it may give us a steel that will decrease the wrecks caused by the so-called "mysterious failures" met with on the railroads of this country.

Experiments are also being made on crucible and tool steels with titanium as one of the alloying elements. It seems to give the best results in percentages of from 0.10 to 0.50.

Other Alloying Elements

Some tin steels have been made. These cannot be rolled, if there be more than 1 per cent. of tin present; they are extremely hard and brittle. Annealing has the same effect upon these as upon the

ordinary steels; there is in no case precipitation of the carbon in the state of graphite. Hardening produces martensite only where there is pearlite beforehand; it seems that the ferro-stannide solution of iron does not dissolve the carbon.

In the matter of cobalt-iron alloys, investigations up to a cobalt percentage of 60 have been made. The mechanical properties were but little modified in these, but the breaking strength and the elastic limit cross slowly, while the elongation and the reduction in cross-section are inversely modified. The cobalt steels have no industrial interest and do not present any of the qualities of the nickel steels.

In general, cobalt in steels enters into solution in the iron, and the carbon exists therein—at least in the range of the experiments made—in the shape of iron carbide. The mechanical properties of these steels do not seem to promise any industrial application thereof; they show very clearly the marked difference between tin, titanium and silicium steels on the one hand, and nickel and cobalt steels on the other.

Boron has a great affinity for oxygen and combines with it in the form of boric acid which is a strong flux. It appears to be a promising element for experimenting with as the materials from which it is made are cheap and it should be produced at a reasonable price.

Calcium also from its chemical composition would indicate that it would act as a remover of oxygen and it might have some action on the removal of phosphorus and sulphur. The metal melts easily and could be readily mixed with the steel.

Uranium has also been used in tool steels, but did not give the results obtained by other elements; thus its use has been very limited.

Heat Treatment of Steel

Annealing, Hardening, Tempering and Carbonizing with the Changes in Structure Shown by the Microscope and Its Effect

In working steels it is very important that they be properly heat-treated, as poor workmanship in this regard will produce working parts that are not good even though the stock used be the highest grade of steel that is procurable. And by improperly heat-treating them it is possible to make high-grade steels more brittle and less able to support a load or withstand stresses than ordinary carbon steels. All steels are improved in tensile strength, elastic limit, elongation or reduction of area by annealing, hardening or tempering them. The different treatments are divided into three distinct classes, the first of which is hardening, the second annealing and reheating, and the third case-hardening, carbonizing or cementing.

The theory of heat treatment rests upon the influence of the rate of cooling on certain molecular changes in structure occurring at different temperatures in the solid state. These changes are of two classes, critical and progressive; the former occur periodically between certain narrow temperature limits, while the latter proceed gradually with the rise in temperature, each change producing alterations in the physical characteristics. By controlling the rate of cooling, these changes can be given a permanent set, and the physical characteristics can thus be made different from those in the metal in its normal state.

Factors Which Influence Results

The results obtained are influenced by certain factors as follows: First, the original chemical and physical properties of the metal; second, the composition of the gases and other substances which come in contact with the metal in heating and cooling. Third, the time in which the temperature is raised between certain degrees, or the temperature-rise curve. Fourth, the highest temperature attained. Fifth, the length of time the metal is maintained at the highest temperature. Sixth, the time consumed in allowing the temperature to fall to atmospheric, or the temperature-drop curve.

The third and sixth are also influenced by the size and shape of the piece; by the difference in temperature between it and the heating and cooling mediums; by the thermal capacity and conductivity of the latter, each of which may vary widely within the temperature range to which it will be subjected.

The first, second, third and fourth are but elements of the heating process, and the sixth of the cooling. The method of heating the alloy steels is very important, as mechanical injuries are liable to occur, in the external layers of the metal as well as the internal, from a too rapid rise in the temperature, especially at the start.

Highest Safe Temperature

The highest temperature that it is safe to submit a steel to for heat-treating is governed by the chemical composition of the steel, and this temperature should be about 40 degrees Fahrenheit above the highest point of transformation in the steel considered. Thus pure carbon steel should be raised to about 1650 degrees Fahrenheit, while some of the high-grade alloy steels may safely be raised to 1750 degrees Fahrenheit, and the high-speed steels may be raised to just below the melting point. It is necessary to raise the metal to these points so that the active cooling process will have the desired effect of checking the crystallization of the structure. If raised above these temperatures, in an oxidizing atmosphere, the surface of the piece becomes covered with a scale of iron oxide and oxidation extends to the elements combined with the iron.

When these oxides remain within the metal, they tend to form a film of separation between the metallic grains, thus destroying the cohesion between them, and the metal is said to be burned. After burning, it cannot be brought back to its former strength without remelting. If the temperature is maintained within the crystallogenic zone, disaggregation proceeds, so that the longer it is subjected to this temperature and the higher the temperature the less homogeneous it becomes and the coarser its grain after quenching. Steel in this state is called overheated. It can be partially returned to its former strength by repeated forging above the critical temperature, followed by positive quenching or it may be restored by a proper method of heat-treating.

When, as always happens, the grain has become coarsened by overheating it must be refined again to bring it back to its original condition. To do this it is necessary to heat the metal to the point where a new crystal-size is born as the coarsening of the grain is merely a growth of the crystals and these crystals grow with every increase in the temperature above the point necessary for hardening or annealing.

If we barely pass the degree of temperature at which this new crystal-size is born we will obtain the smallest grain size that the steel is capable of. This temperature varies with the carbon content of the steel. The higher the percentage of carbon the lower the degree of temperture that will be required; a law-carbon steel must be heated to 1650 degrees Fahrenheit, a 0.40 per cent. carbon steel to 1475 degrees Fahrenheit, and so on. Some of the special alloying ma-

terials also effect this temperature as well as the size of the grain.

Furnaces and Their Fuels

Owing to the nature of most steels they must be handled very carefully in the processes of annealing, hardening and tempering; for this reason much special apparatus has been installed in the past few years to aid in performing these operations with definite results.

This apparatus is divided into two distinct classes, that is, the apparatus for heating the metal, and that for cooling. In heating the metal four methods are used, namely, furnaces using solid fuel, liquid fuel, gaseous fuel and electricity.

Furnaces using solid fuel such as coal, coke, charcoal, etc., are the most numerous and have been used the longest. These furnaces consist of a grate to place the fuel on, an arch to reflect the heat and a plate to put the pieces on. The plate should be so arranged that the flames will not strike the pieces to be heated, and for that reason some use cast-iron or clay retorts which are open on the side toward the doors of the furnace. In this manner the work is protected, to a large extent from the products of combustion which are liable to cause oxidation, sulphuration, etc., and thus destroy the surfaces of the work. The doors should open and close very rapidly, so as to keep the cold air out of the furnace and facilitate the manipulation of the work. For these reasons a furnace of the design similar to that shown in Fig. 7 is used considerably owing to its having sliding doors with weights to counterbalance them.

The disadvantage of this style of furnace is that it is almost impossible to keep a constant temperature, and as a chimney must be provided, much heat is lost through that. By not being able to keep a constant temperature it is impossible to measure the heat with a pyrometer and the heat must be judged entirely by the color as seen with the eye which makes the results depend entirely on the skill and experience of the workman. Also the atmospheric air and gases generated by the combustibles or a combination of both come in contact with the white hot metal. These are liable to cause the metal to lose some of its carbon content, especially at corners or on thin delicate sections, from the oxidizing influence of the oxygen in the air or other causes. The combustibles are also liable to contain injurious ingredients, such as sulphur which are liable to enter the steel.

Liquid Fuels

Furnaces of the above type, that is those which have open fires, which use liquid fuels are not very numerous at present, but are being increased in number every day, owing to the ease with which the fire is handled and their cleanliness over the coal, coke or charcoal fire.

Crude oil and kerosene are the fuels generally used in these furnaces owing to their cheapness and the fact that they can be obtained nearly everywhere. These fuels are usually stored in a tank near the furnaces and are pumped to them or flow by force of gravity. Between the tank and furnace is located a coil of pipe through which the fuel flows and over which a stream of water is flowing to keep the liquid at a low, even temperature when it enters the burners, which are located in the furnace.

With this fuel hardly any work is required to keep up the fires as they can be lighted in the morning and the temperature regulated by the turning of a few valves and cocks. A more even temperature can thus be kept in the furnace than with the solid fuels, but the opening of the doors to handle the work reduces the temperature of the furnace the same as with the solid fuels. The action of the gases of the combustibles, or the oxygen of the atmosphere, in attacking the white hot metal gives the same disadvantages.

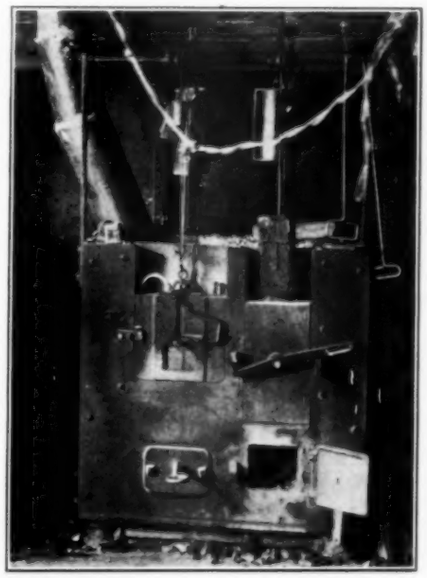


FIG. 7. HARD FUEL FURNACE FOR HEAT-TREATING STEEL

Heating in Liquids

Furnaces using liquid for heating consist of a receptable to hold the liquid, which is heated by coal, oil, gas or any other economical means; the liquid is kept at the highest temperature to which the piece should be heated. The piece should be heated slowly in an ordinary furnace to about 800 degrees, after which it should be immersed in the liquid bath and kept there long enough to attain the temperature of the bath and then removed to be annealed or hardened.

The bath usually consists of lead, although antimony, cyanate of potassium, chloride of barium, a mixture of chloride of barium and chloride of potassium in the proportion of 3 to 2, mercury, common salt and metallic salts have been used successfully.

This method gives good results, as no portion of the piece to be treated can reach a temperature above that of the liquid bath; a pyrometer attachment will indicate exactly when the piece has arrived at that temperature, and its surface cannot be acted upon chemically. The bath can be maintained easily at the proper temperature and the entire process is under perfect control.

When lead is used it is liable to stick to the steel and retard the cooling of the spots where it adheres. Impurities such as sulphur, etc., are liable to be absorbed by the steel and thus alter its chemical composition. With high temperatures lead and cyanate of potassium throw off poisonous vapors which make them prohibitive, and even at comparatively low temperatures these vapors are detrimental to the health of the workmen in the hardening room. The metallic salts, however, do not give off these poisonous vapors, hence are much better to use for this purpose, but many times the fumes are unbearable.

Gases for Fuels

Furnaces using gaseous fuel are very numerous and are constructed so they can use either natural gas, artificial gas, or producer gas. They are very easy to regulate and if well built are capable of maintaining a constant temperature within a wide range.

In first cost this style of furnace is greater than that of the solid fuel furnaces, but where natural or producer gas is used the cost of operating is so much less that the saving soon pays for the cost of installation. Artificial gas, however, is more expensive than the solid fuels and is only used where high-grade work demands the best results from heat treatment. Producer-gas furnaces may be supplied with gas from a central producer plant or may have a separate producer of their own. The latter is only economical when large furnaces or a number of small ones are required to turn out the work.

By using special apparatus a large portion of the heat, which is carried away in the chimney of other furnaces, is saved and utilized in heating the air of combustion which is admitted to the furnace.

Results which are very uniform are obtained with the gas furnaces and it is much easier to maintain a constant temperature with liquid baths than in a solid fuel furnace, or a metal retort may be used to place the work in for the purpose of keeping it away from the gases of combustion, with a greater assurance that the work in it will be raised to the proper temperature and maintained at an even temperature for a given length of time.

Pyrometers can be used very easily to measure the heat with this style of furnace. Thus definite results may be obtained in the degree of temperature without depending on the skill or knowledge of the workman to as great an extent as with the furnaces using coal, coke or charcoal for fuel.

Electric Furnaces

While the cost of electricity as a fuel for heating furnaces is probably greater than that of any of the others, the results obtained by its use in heat-treating steel are better than that of any known method.

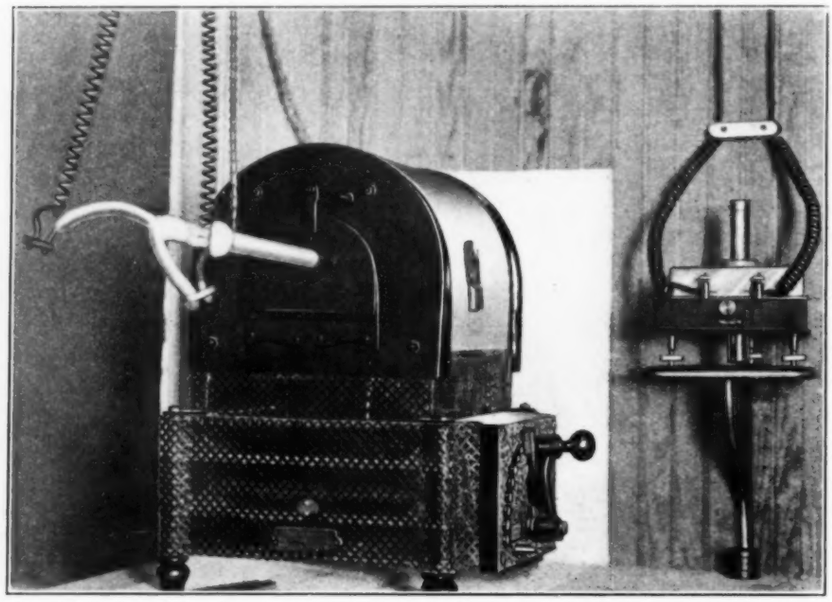


FIG. 8. EXPERIMENTAL ELECTRIC FURNACE FOR HEAT-TREATING STEEL

The electric furnaces might be placed in two classes; namely, those which use electrodes and those which have the receptacle wound with platinum, nickel or ferro-nickel wire which is covered with some product that will protect it from silication due to the silicates of the receptacle, calcium aluminate being one of these.

Both of these furnaces are lined with some refractory material, but the latter is not practical for large furnaces, hence is used for very small work or for experimental purposes. This style of furnace is shown in Fig. 8.

In Figs. 9 and 10 is shown an electric furnace in which the electrodes are used as a magnet to hold the work until it reaches the point of recalescence which is non-magnetic. The magnetic attraction is then broken and the work can drop into a bath for quenching. This will give it the greatest hardness it is possible to give the steel and at the same time make the grain as fine and the molecules as adhesive as they can be made by heat treatment.

Electric furnaces similar to that shown in Fig. 11 are used to heat the liquid baths described above. In this furnace the metallic salt baths seem to be the most appropriate. These salts completely prevent contact between the white hot steel and the air during the heating, as well as during the passage to the quenching bath. The steel being uniformly covered with a protective coat of the salts during the passage of the steel from the furnace to the quenching bath. On immersion in the cooling liquid this coating immediately leaves it and the surface of the steel always appears smooth. The formation of scale is entirely prevented even after tempering.

The source of heat being inside the bath in this furnace the heat is evenly distributed and the temperature of the bath is uniform throughout every part of it. High temperatures are as readily obtained and with as little watchfulness as relatively low ones, which makes it easy to determine the temperatures desired in heat-treating the steel.

The pyrometer can be used successfully in measuring the temperature of the bath. As the current traversing the bath varies, the temperature and the primary current remain constant. One careful determination with the pyrometer is enough to afterward judge the temperature of the bath entirely by the current.

This style of furnace requires from 15 to 40 minutes to start according to the size. The cold furnace can be started by passing the current through a piece of carbon until this becomes white hot and melts the surrounding salt which then becomes conductive and in turn melts the whole mass. When finished using the current is shut off and the salt bath can be kept molten for a long time by putting a cover over it.

Apparatus for Cooling

The cooling apparatus is divided into two classes, that is, baths for hardening

FIG. 9. MAGNETIC FURNACE FOR HARDENING STEEL

and the different appliances for annealing.

The baths for quenching are composed of a large variety of materials. Some of the more commonly used are as follows, being arranged according to their intensity on 0.85 per cent. carbon steel: Mercury; water with sulphuric acid added; nitrate of potassium; sal ammoniac; common salt; carbonate of lime; carbonate of magnesia; pure water; water containing soap, sugar, dextrine or alcohol; sweet milk; various oils; beef suet; tallow; wax. These baths, however, do not act under all conditions with the same relative intensity, as their conductivity and viscosity vary greatly with the temperature, and their curves of intensity are therefore very irregular and cross each other frequently.

With the exception of the oils and some of the greases, the quenching effect increases as the temperature of the bath lowers. Sperm and linseed oils, however, at all temperatures between 32 and 250 degrees F. act about the same as distilled water at 160 degrees.

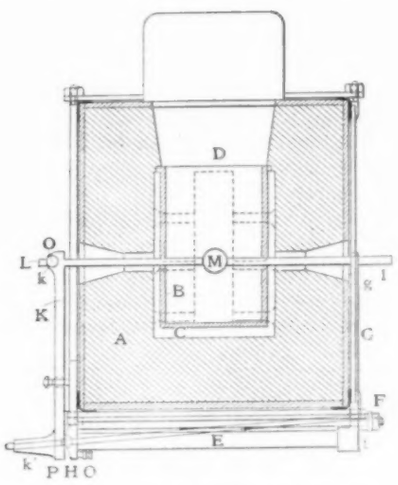


FIG. 10. SECTION THROUGH MUFFLE

The baths for hardening which give the best results are those in which some means are provided for keeping the liquid at an even temperature. Of course where but few pieces are to be quenched, or a considerable time elapses between the quenching of pieces, the bath will retain an atmospheric temperature from its own natural radiation. Where a bath is in continuous use, for quenching a large number of pieces throughout the day, some means must be provided to keep the temperature of the bath at a low even temperature. The hot pieces from the heating furnace will raise the temperature of the bath many degrees, and the last piece quenched will not be nearly as hard as the first.

Methods of Keeping Baths Cool

When plain water is used it is easy to keep the bath cool by providing it with a pipe connecting it to the supply main and an outlet into the drain and thus have a steady flow through the bath. Where a large amount of work is done and the water is paid for at meter rates, as in cities, this might be more expensive than having a large tank at an elevation above the bath and a pump to force the water into it, thus using the water over and over again.

This flowing of the liquid would do away with the necessity of agitating the steel in the bath, as when it is of the ordinary stationary kind, owing to the flowing liquid carrying away the coating of vapor which is liable to form around the piece and prevents its cooling rapidly.

A hole in the center of the bottom with an outlet on top is not a very good arrangement as the cool current striking the bottom side of the piece is liable to cause it to warp. If the cool liquid is taken in at the bottom it should be taken in through several openings. A good method is to have the inlet covered with a spherical piece of sheet metal punched full of small holes that would deliver the liquid in fine streams similar to that of a sprinkling can. This would send the cool liquid to all parts of the bath.

A still better arrangement would be to have an extra inner wall with a large number of fine holes punched in the sides and solid at the bottom. This would cause the cool liquid to flow in from all sides which would give the bath a complete agitation and subject the pieces to less irregularity of temperature and would therefore reduce the tendency of the pieces to spring or warp from not cooling equally on all sides.

With liquids, other than water this method is not practical owing to the large volume of liquid necessary for the bath and its consequent high cost. Then again the losses from evaporation might be too great. For this kind of bath a water-jacketed receptacle could be used and a steady current of cold water kept flowing through it or the bath could be fitted with a coil of pipe over the bottom and around the sides through which a circulation of cold water could be maintained and thus keep the bath cool by radiation. Another method which has been used successfully is to blow fine sprays of air through the bath from the bottom similar to the method used in the bessemer converter on molten steel.

With many classes of work a bath whose liquid is stationary and has no mechanical means of cooling, can be used by having the volume of the bath large enough to work off the heat left by the quenching of the pieces. Baths of this character are sometimes fitted with a moving platform which carries the work through the bath and out of it after cooling sufficiently. Some of these also carry the work through a pickling bath after it has been quenched.

With many steels a dual quenching gives the best results, that is, the metal is quenched to a certain temperature in one bath and then immersed in the second one until completely cooled, or it may be cooled in the air after being quenched in the first bath. For this a lead bath, heated to the proper temperature, is sometimes used for the first quenching.

Apparatus for Annealing

The appliances for annealing are nearly as numerous as the baths for quenching, and where a few years ago the ashes from the forge were all that were considered necessary for properly annealing a piece of steel, today many special preparations are being manufactured and sold for this purpose.

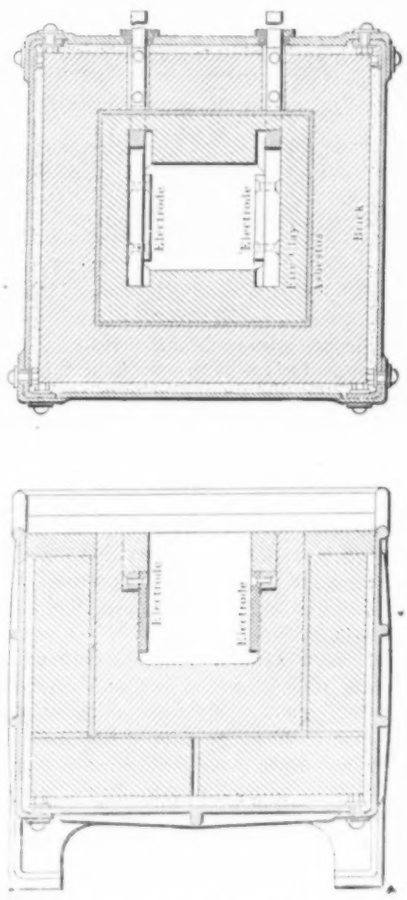


FIG. 11. ELECTRIC FURNACE

The more common materials used for annealing are powdered charcoal, charred bone, charred leather, slacked lime, sawdust, sand, fire clay, magnesia or refractory earth. The piece to be annealed is usually packed in a cast-iron box similar to Fig. 12, using some of these materials or combinations of them for the packing, the whole is then heated in a furnace to the proper temperature and set aside, with the cover left on, to cool gradually to the atmospheric temperature.

For certain grades of steel these materials give good results; but for all kinds of steels and for all grades of annealing, the slow-cooling furnace no doubt gives the best satisfaction, as the temperature can be easily raised to the right point, kept there as long as necessary, and then regulated to cool down as slowly as is

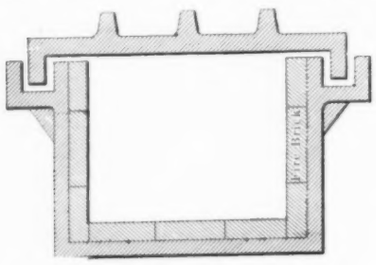


FIG. 12. CAST-IRON BOX FOR ANNEALING

desired. The gas, oil or electric furnaces are the easiest to handle and regulate.

Annealing Steel

Theory, Methods, Materials Used and Application

The annealing of steel consists of the thermal treatment used in carrying it above the temperature at which its high est point of transformation occurs, and then allowing it to cool gradually. This point of transformation is that at which the steel becomes non-magnetic and its physical structure changes. If a pyrometer is used to measure the temperature of the steel in heating or cooling, it will show a point at which the rapid change in temperature ceases for a time and the recording chart will show a line nearly at right angles to that of the rise or fall curve. At this point the change in structure of the metal ceases until all the molecules have become thoroughly non-magnetic and a new crystal-size of grain is born. This refines any large or coarse crystals which may have been produced in the steel by former methods of heating or working. This change in structure releases any strains which may have been set up in the metal and allows them to readjust themselves so that they are equalized throughout all parts of the piece.

This temperature of the point of transformation varies considerably in different steels. This is shown by Chart 6, which was plotted from a recording pyrometer chart.

Another operation is sometimes called annealing, that is, that of partially destroying the effects of sudden cooling or quenching. In this the annealing temperature is kept below the highest point of transformation. This operation is more properly named tempering and will be dealt with under that title.

As a general rule all steel should be annealed after every process in manufacturing which tends to throw it out of its equilibrium, such as forging, rolling and rough machining, so as to return it to its natural state of repose. It should also be annealed before quenching, case-hardening or carbonizing.

Effect on Hammered Steel

Should we start with an annealed or freshly poured ingot of steel and subject it to a hammering process such as forging, the hammering will have a tendency to crush the crystals forming the mass of the metal, whether it be hammered hot or cold. This will bring the particles of the metal closer together, but there is a limit to the increase in the density which can be attained in this manner as a great deformation is eventually given the metal.

This metal is called "hammer-hard" and a large number of metals will show about twice the tensile strength after being hammered to the limit of compression that they will when in the normal state.

The limit of compression, however, is difficult to gage and if the limit is passed as it usually is in practice, the hammering is liable to cause coarser crystals to form where it has squeezed out from under the hammer blows. To remove this crystallization and refine the grain, annealing has to be resorted to.

Thus certain laws have been formulated which hold good on annealing-hammered metal and these are as follows:

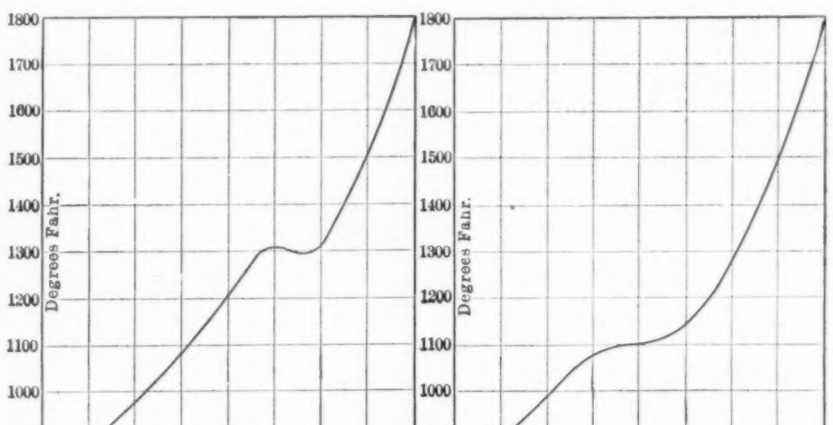


CHART 6

First: Annealing is not an instantaneous phenomenon; its effects become accentuated in proportion to its duration, thus being rapid at the start and becoming slower and slower; the decrease in the hammer hardness tends toward a fixed limit for each temperature.

Second, the higher the annealing temperature, the lower will be the limit toward which hammer hardness tends; in practice the more rapidly will this limit be attained.

Third, above a certain temperature, annealing is practically complete; the tensile strength has reached the minimum value possible for the metal and a renewed increase in temperature does not produce any new reduction.

Beginning with this temperature another change may take place which has been named "crystallization of annealing." This phenomenon becomes more pronounced with the duration of the annealing process and has for its effects the diminishing of the reduction of area. If very pronounced the reduction entirely disappears, simultaneously with the tensile strength and the elongation.

Another phenomenon might be mentioned here and that is spontaneous annealing. Thus if hardened steel be left to itself it will anneal of itself, the only factor entering into this phenomenon being time. As this time, however, covers such a long period and the annealing process is such a slow one the principle is of no importance from a practical standpoint.

Practical Rules

From the above may be deduced three practical rules to adopt in annealing steel, these being:

First, a quenched or hammered piece must be heated to a temperature above its highest point of transformation, but as close to this point as possible.

Second, this temperature must be retained long enough to allow the entire piece to reach an even temperature, but it must not be prolonged beyond it.

Third, the rate of cooling must be sufficiently slow to prevent any hardening taking place, not even superficial hardening.

In applying these rules we find that extra low-carbon steel should be annealed at 1650 degrees Fahrenheit and extra high-carbon steels at 1375 degrees. The time of annealing varies with the size and

shape of the piece as well as with the work which it has to perform. The more important this work is, the more prolonged should be the annealing process. Intricate pieces with thin and thick sections have to be handled with extra care, and sometimes materials are brought into use to retard the cooling of the thin section faster than the thick one, as ordinarily a thin section will cool quickly in comparison with the thick one and consequently be that much harder.

To insure slow cooling, when a slow cooling furnace is not obtainable, the work should be packed in some non-carbonizing material, in an iron box lined with fire brick similar to the one shown by Fig. 12. The whole can then be heated in a furnace and set out on the floor to cool as the thickness of the materials prevents rapid cooling. This will also tend to prevent the pieces from scaling as they do not come in contact with the oxidizing influences of the atmosphere. When the temperature of the pieces has dropped to 550 degrees Fahrenheit they may be removed from the box as the annealing process has ceased, and there will be no danger of their air-hardening.

Why High Temperatures are Harmful

As it is generally agreed upon that steel should not be heated much above the point of transformation in the annealing process it would be well to give the reasons. The nine laws formulated by Prof. H. M. Howe, of Columbia University, after many tests by himself and others, cover the ground so thoroughly that they are here given.

First law: When a given steel is heated to a temperature above the highest point of transformation the grain assumes a definite size characteristic of the temperature. We call this the normal size.

Second law: The size of the grain increases in proportion to the temperature counted from the highest point of transformation.

Third law: The influence of the temperature is the more pronounced the greater the carbon component of the steel. In other words for the same annealing temperature the normal grain of the steel is coarser, the greater the carbon component.

Fourth law: If a steel is raised to a temperature above its highest point of transformation and if in consequence of previous treatment the steel possesses a finer grain than the normal, the grain of the metal becomes coarser until it is equal to the normal grain.

Fifth law: In order to attain the normal grain for any temperature, the metal must be maintained at this temperature for some time.

Sixth law: If the metal is heated to a certain temperature and has assumed the normal grain for this temperature, and if it is then maintained at a somewhat lower temperature, but still above the point of transformation, the size of the grain is not reduced, provided the metal is not reduced below the point of transformation.

To illustrate this, a steel is carried to 2200 degrees Fahrenheit; the grain then becomes of the size characteristic of this temperature; if the temperature is then lowered to 1650 degrees there will be no change in the size of the grain. It would be quite different, however, if instead of cooling the metal directly to 1650 degrees it had been cooled down to 925 degrees, which is much below the point of transformation and then re-heated to 1650 degrees.

Seventh law: If the temperature of a steel remains below the point of transformation its grain does not change.

Eighth law: If a steel is cooled slowly after having been heated to above its point of transformation, it possesses substantially the same grain as that which it possessed at the maximum temperature.

Ninth law: From this it may be deduced that the grain of a metal after annealing is the coarser the higher the temperature to which it has been raised is above the point of transformation.

Effect of Annealing on the Strength

While the relation existing between the annealing temperature and the mechanical properties has not been fully determined, enough is known to establish certain rules which are beneficial in a practical way. A coarse-grained metal is more brittle than a fine-grained, and therefore any change in the size of the grain will affect the strength of the steel. As the annealing temperature affects the size of the grain, a steel that is heated to a variable temperature and slowly cooled will alter its mechanical properties about as follows:

First, the tensile strength slightly increases with the increase in temperature up to 2375 degrees F., after which it rapidly decreases. This makes it necessary to keep the annealing temperature a little above, but as close to the point of transformation as possible.

Second, the elastic limit passes through a minimum at the highest point of transformation but increases slightly when the temperature passes this point, and then decreases as this point is exceeded by 175 degrees F. The slower it is cooled from the point to which it has been heated the lower will be the elastic limit.

Third, the elongation decreases as the annealing temperature increases, and this decrease is very important when the temperature attains 2375 degrees Fahrenheit.

With these points taken into consideration it will be seen that the annealing of steels cannot be too carefully done if the best results are to be obtained, and especially is this so of the high-grade alloy steels which are being used more and more every day.

It has been shown that if the heat treatment is carried out in a manner that will produce sorbite, the tensile strength is much higher and the elongation is slightly greater than when the metal is simply annealed. To obtain sorbite it is necessary to quench above the point of transformation and then reheat to from 575 to 1300 degrees F., according to the composition of the metal and the hardness desired, then cool in air or in water.

The furnaces used for annealing are the same as those used for other heat-treating operations unless enough pieces are annealed to put in a slow-cooling furnace and then it is only the accessories that are different.

Hardening Steel

Alterations in Structure, Influence of Composition and Results Obtained

Hardening is generally understood to mean the heating of the metal to a high temperature and then plunging it into a bath for the purpose of suddenly cooling it. While this definition holds good on most steels, a few alloying materials now used reverse this and make the metals air-hardening, that is, their hardest and toughest state is obtained by a slow-cooling process rather than a sudden one.

Two reasons might be assigned for the desirability of hardening steel and these are: First, to give the steel a cutting edge such as is required for all cutting tools, and, second, to alter the static strength and dynamic qualities of the metal so it will give the best results for the moving parts of machinery.

In this second case steels may be altered by quenching from a high temperature and tempering, to an extent that will greatly improve their wearing qualities, tensile strength, elastic limit, magnetic qualities or resistance to shock and yet not be capable of attaining a hardness which will not allow a file to cut it; this being the usual test of hardness applied in the shop. Thus, generally speaking, all steels may be hardened although some may have a low carbon content.

To harden steel, therefore, it is necessary that the heating produces a change in the structure and that the quenching which follows the heating will retain a whole or a part of the elements produced by this change of structure. It is therefore necessary, as in annealing, that the temperature of the steel be raised to a point slightly above the point of transformation.

As the point of transformation varies with different ingredients which are alloyed with steel it is necessary to find out where this point is in the steel to be hardened. A steel may be heated to 1300 degrees Fahrenheit—which is above the

point of transformation in some steels—and no change in structure will take place and therefore no results in hardness will be obtained. If the same piece is heated to 1650 degrees—which we will consider the point of transformation in this piece—the intermolecular transformation, which consists of the passage of the carbon from the combined into the dissolved state will take place and the steel will assume the hardest state it is capable of, if properly cooled.

Thus the factors which have an influence on the results of hardening are: First, the nature and composition of the metal; second, the temperature of the metal when quenched and, third, the nature, volume and temperature of the quenching bath.

Microscopical Examination

The nature of these different factors is shown to a large extent by quenching the metal at different temperatures, polishing the surface, attacking it with picric acid,

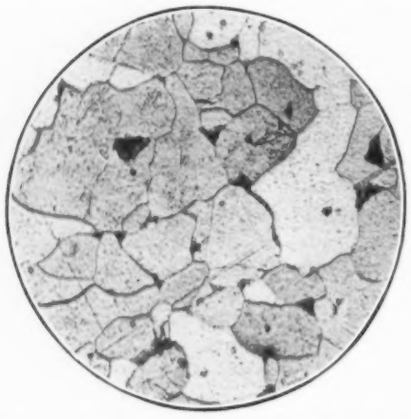


FIG. 13. FERRITE WITH VERY THIN CONTINUOUS CEMENTITE SKELETON. LOW CARBON. MAGNIFIED 250 DIAMETERS

tincture of iodine, hydrofluoric acid or other etching materials and examining it under a microscope.

Steel containing less than 0.85 per cent. carbon will show small dark masses, if etched with picric acid, which are the more numerous the closer the carbon content is to 0.85 per cent. At this percentage they cover the entire surface. These masses show alternate layers which are ferrite—pure iron—and an iron carbide called cementite. The ferrite being the softest constituent of steel, it will indent when polished and the cementite will stand out in relief.

Ferrite is the carrier for all of the alloying elements in the high-grade steels. It is the principal constituent of all steels and the predominating one in low-carbon steels. It has one peculiarity which is very important and that is that when heated to about 1400 degrees Fahrenheit it undergoes a sudden change which is shown by its absorption of heat. It then loses nearly all of its power to attract a magnet as well as changing its specific heat and several other properties. No alteration, however, takes place in its chemical composition. The name of beta iron has been given to it at this point.

If this beta iron be then heated to about 1650 degrees Fahrenheit it again shows it by absorbing heat and its properties are again changed. Here it has been named gamma iron. Gamma iron differs from beta in the electrical conductivity and is far less brittle.

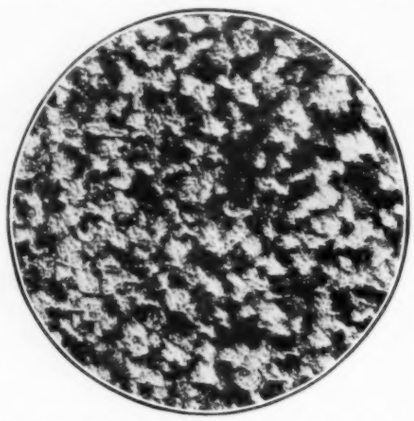


FIG. 14. FERRITE, WHITE, CEMENTITE, BLACK. MAGNIFIED 250 DIAMETERS

These changes occur both in the rise and fall of the temperature and have been called by different metallurgists the points of transformation, the recalescence points and the critical temperatures; all of which mean the same.

Below beta iron or at atmospheric temperature it is called alpha. The names alpha, beta and gamma are taken from the names of the first three letters in the Greek alphabet.

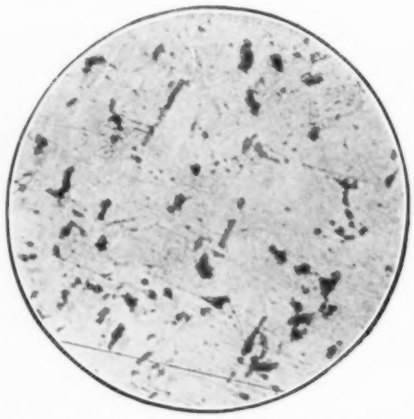


FIG. 15. FERRITE MATRIX WITH SEPARATED PEARLITE ISLANDS, MAGNIFIED 250 DIAMETERS

Ferrite is shown in Figs. 13, 14, 15, 16 and 19.

Cementite and Pearlite

Cementite is the carbide of iron and is expressed by the following formula: Fe_3C, which means ferrite—which is pure iron—3 atoms for every one atom of carbon.

It is the second constituent in importance in steel—ferrite being first—and is very hard and brittle. Practically all of the carbon is present in this form and it usually crystallizes in thin flat plates. Cementite does not exist in pure iron, which contains no carbon, and of itself contains about 6.6 per cent. of carbon which is about one-fifteenth of it.

Two extremes of cementite formation are shown in Figs. 13 and 14.

Pearlite is an intimate mixture of ferrite and cementite and consists in general of 32 parts ferrite to 5 of cementite, which gives it the appearance of mother of pearl, from which it derives its name. It exists in a lamellar formation, which is alternate plates of ferrite and cementite, or in a granular formation, which is intermingling grains of ferrite and cementite. If commercial steels were free of graphite they would hold nearly fixed proportions of ferrite, cementite and pearlite, all combined, as these steels seldom exceed 1.40 per cent. carbon. A

FIG. 16. FERRITE, WHITE. PEARLITE, BLACK. MAGNIFIED 250 DIAMETERS

normal steel, containing 0.85 per cent. carbon, would then consist of 100 per cent. pearlite, while below this carbon content the whole carbon would be divided into pearlite and excess ferrite. If the total carbon exceeds 0.85 per cent. and is all combined, the excess would be cementite instead of ferrite and the cementite would increase with the carbon. Pearlite is shown in Figs. 15 and 16.

Martensite and Hardenite

Leaving the steels which have been cooled slowly, and taking up those which have been quenched from a given temperature and hardened we find that a steel containing about 0.85 per cent. carbon, if heated to about 1400 degrees Fahrenheit and quenched, will show under the microscope extremely fine lines intersecting each other in the direction of the sides of an equilateral triangle. This constituent has been named martensite in honor of Professor Martens. It is the principal constituent of all ordinary hardened steels which have a carbon content above 0.16 per cent., and tempered steels

owe their quality of hardness to it. It is so hard that a needle will not scratch it after the metal has been polished.

In steels containing over 0.85 per cent. carbon the martensite is said to be saturated and shows slightly different under

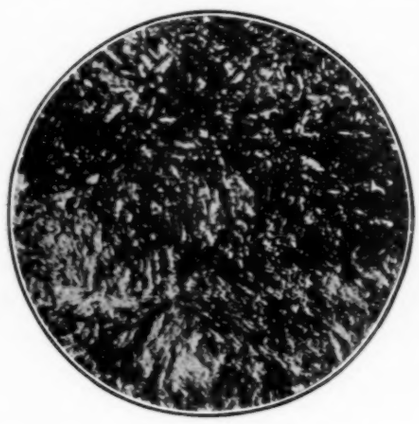


FIG. 17. MARTENSITE FORMATION MAGNIFIED 250 DIAMETERS

the microscope. This has been called by some hardenite, which word is often used in French and German books.

Martensite is shown in Figs. 17 and 18.

SORBITE

Sorbite is a constituent between cementite and pearlite and chiefly differs from the pearlite and cementite by the crystals of these segregating and not quite perfectly developing. This is drawing the line pretty fine, but the sorbitic structure is finer than the pearlitic and it is considered the extreme opposite of the crystalline structure. The sorbitic structure is considered necessary in metals which have to resist wear and erosion and the natural formation of this

FIG. 18. MARTENSITE MAGNIFIED 200 DIAMETERS
(By Prof. Bradley Stoughten)

structure is rendered possible by the addition of certain alloying elements. In hardened steel, sorbite is considered as the transition from cementite to martensite.

The sorbitic structure may be obtained when the cooling is not as rapid as that of quenching, but still much faster than the slow cooling for annealing; by quenching immediately below, or just at the end of cooling through the critical range; by cooling pretty fast through the critical range without actual quenching; or by rapidly cooling the steel and then re-heating to about 1100 degrees Fahrenheit.

Sorbite is not clearly defined in microphotographs, but Fig. 19 shows it fairly well with ferrite.

AUSTENITE

High-carbon steels which contain over 1.10 per cent. of carbon and are suddenly cooled from a temperature of 2000 degrees Fahrenheit, will show a constituent in addition to martensite which may be distinguished from it by a different color. If etched with nitrate of ammonia, or with a 10 per cent. solution of hydrochloric acid, it will show white.

This constituent is softer than martensite and is easily scratched with a needle.

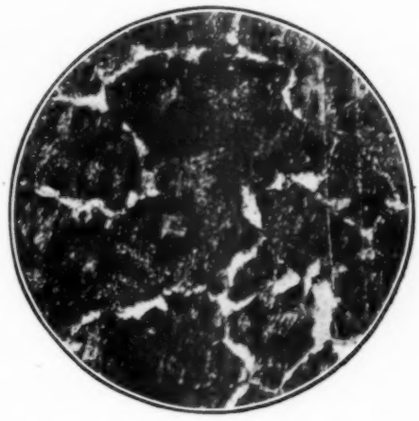


FIG. 19. FERRITE AND SORBITE MAGNIFIED 250 DIAMETERS

It is essentially a conglomeration of ferrite and cementite. It has been named austenite after Prof. Robert Austen.

Austenite is difficult to preserve throughout the whole structure of the steel. Quenching in a bath which has a temperature below the freezing point or any other means which will cool it rapidly will aid in preserving it. Tempering the metal afterward, however, loosens the austenite and it is not of much practical use owing to the high temperature at which it is obtained.

Fig. 20 shows the austenite formation.

TROOSTITE

If steel is quenched during or just above its transformation in a bath of little activity, such as oil, or if it is hardened in the usual way and then tempered, we can obtain a constituent which will show jet black if polished and etched with picric acid, or if etched with a tincture of iodine it will show white. This has been named troostite in honor of Prof. M. Troost.

Troostite is also softer than martensite as it can be scratched with a needle. It holds some ferrite, austenite or cementite or a combination of these and is

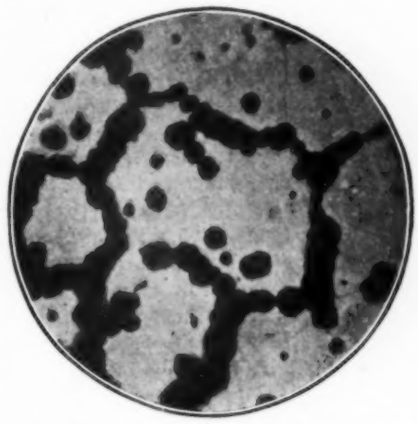


FIG. 20. AUSTENITE, WHITE. TROOSTITE, BLACK. MAGNIFIED 50 DIAMETERS
(By Prof. Wm. Campbell)

found plentifully in tempered steels as it is a product of the usual tempering operations. It shades gradually into the sorbite, but is very sharp in its divisions from martensite.

Troostite is shown black in Fig. 20, and white in Fig. 21.

SUMMARY

In subjecting steel to different heat treatments we can change the constituents from pearlite to martensite or hardenite, sorbite, austenite and troostite and back again through these different stages and by examining them with the microscope we can judge very closely the treatment they have been subjected to.

By making these changes we also

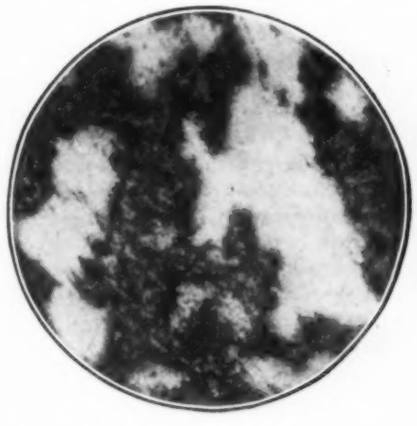


FIG. 21. MARTENSITE, BLACK. TROOSTITE, WHITE. MAGNIFIED 350 DIAMETERS
(By Prof. H. C. Boynton)

change its constitution, its static strengths and its dynamic properties. This is where the practical application of this knowledge aids the engineer or designer in designing the moving, as well as other, parts of machinery so as to get the best

results from the smallest quantity of material.

Effect of Composition and Hardening

The constitution of a given steel is not the same in the hardened as in the normal state owing to the carbon not being in the same state. In the annealed or normal steel it is in a free state, while in a hardened steel it is in a state of solution which we may call martensite; and this contains more or less carbon according to the original carbon content of the steel. The composition, and therefore the mechanical properties, depend principally upon the carbon content, the mechanical properties being changed slowly and gradually by an increase in carbon.

This is best shown by Table 1 in which it will be seen that the tensile strength and elastic limit gradually increased with the increase in the percentage of carbon, both in the annealed and hardened state while the elongation gradually decreased. These tests were made with a bar ½ inch in diameter and 4 inches in length. It will also be seen that there was considerable change in the steels which were too low in carbon to be made so hard that they could not be filed. The reduction in elongation when the test bars were heated and quenched showed that the metal was harder than when in the annealed state.

	Case Hardening Steel.	Very Low Carbon.	Low Carbon.	Medium Carbon.	High Carbon.	Very High Carbon.
Carbon	0.10	0.14	0.23	0.52	0.60	0.72
Silicon	0.09	0.05	0.15	0.18	0.10	0.17
Manganese	0.19	0.33	0.45	0.35	0.40	0.38
Phosphorus	0.016	0.023	0.091	0.021	0.035	0.03
Sulphur	0.025	0.052	0.062	0.043	0.025	0.06
MECHANICAL PROPERTIES WHEN ANNEALED						
Tensile Strength, (in pounds per square inch)	60,300	61,500	66,500	97,800	116,400	130,700
Elastic Limit, (in pounds per square inch)	36,300	35,200	41,200	52,600	66,500	75,800
Elongation (percentage in 4 inches)	29	27	26	20	14	9
MECHANICAL PROPERTIES WHEN HARDENED						
Tensile Strength, (in pounds per square inch)	66,400	73,100	99,400	132,100	153,400	180,100
Elastic Limit, (in pounds per square inch)	40,300	39,600	54,000	81,400	102,100	105,500
Elongation, (percentage in 4 inches)	24	22	14	9	4	0

TABLE 1. EFFECT OF COMPOSITION AND HARDENING ON THE STRENGTH

A hardening process that will produce a steel that is as homogeneous as possible is always sought for in practice. This is easily obtained in a high-carbon steel and especially if it contains 0.85 per cent. carbon, by passing the recalescent point before quenching. The desired homogeneity is not so easily obtained, however, in the low-carbon steels as they have several points of transformation. If these are quenched at a point a little above the lowest point of transformation the carbon will pass into solution, but the solution is not homogeneous. To obtain this result it is necessary that the quenching be done from a little above the highest point of transformation. This is higher in the low- than in the high-carbon steels. In practice this calls for a quenching of the low-carbon steels at about 1650 degrees Fahrenheit while a high-carbon steel should be quenched at about 1450 degrees.

Degrees Above Critical Point

The degrees of temperature above the point of transformation that the steel can be heated and still give good results are also quite important. If a piece of steel be quenched from different temperatures above the point of transformation and examined under a microscope we find that the higher we go the coarser will be the martensite, and the lines will be more visible. If we raise this temperature a few hundred degrees above the critical point and quench in a very cold bath, austenite makes its appearance.

In regard to the mechanical properties the higher the temperature above the critical point the lower will be the tensile strength and the less will be the hardness of the steel. The elongation will also show a decrease and this will mean that the steel becomes more brittle with each increase in the temperature.

This coarsening of the martensite, the reduction of both the tensile strength and elongation and the crystallization spoken of some few paragraphs back have led to the conclusions that in practice, 40 degrees Fahrenheit above the highest point of transformation is the extreme limit that steel should be raised to obtain the best results in hardening. The same figure also holds good for annealing.

The following results are obtained in hardening steel: All steels may be hardened, but if the carbon content is over 0.30 per cent. the effect is more pronounced. Hardening increases the tensile strength and elastic limit and reduces the elongation, the effect being greater the greater the carbon content. Quenching at the proper temperature gives the metal a greater homogeneity and this aids the resistance to shock, especially in low-carbon steels; steel should not have the hardening temperature raised more than 40 degrees above the highest point of transformation, as beyond that it no longer has the same qualities.

Hardening Bath

As it is necessary to maintain the metal in the state it was at the moment quenching begins, the quenching bath is a very important part of the process of hardening. The rate of cooling is never swift enough to secure perfection and the intermolecular transformation will be more or less complete according to the rate of cooling. The better the bath the nearer to perfection we will be able to arrive.

In hardening steels the influence of the bath depends upon its temperature, its mass and its nature; or to express this in another way, upon its specific heat, its conductivity, its volatility and its viscosity. With other things equal, the lower the temperature of the bath, the quicker will the metal cool and the more pronounced will be the hardening effect. Thus water at 60 degrees will make steel harder than water at 150 degrees, and when the bath is in constant use the first piece quenched will be harder than the tenth or twentieth, owing to the rise in temperature of the bath. Therefore if uniform results are to be obtained in using a water bath, it must either be of a very large volume or kept cool by some mechanical means. In other words, the bath must be maintained at a constant temperature.

The mass of the bath can be made large so no great rise in temperature is made by the continuous cooling of pieces, or it can be made small and its rise in temperature used for hardening tools that are to remain fairly soft, as, if this temperature is properly regulated, the tool will not have to be re-heated and tempered later, and cracks and fissures are not as liable to occur.

Another way of arriving at the same results would be to use the double bath for quenching, that is, to have one bath of some product similar to salt which fuses at 575 degrees Fahrenheit. Quench the piece in that until it has reached its temperature after which it can be quenched in a cold bath or cooled in the air.

Chart 7 shows the effect of different hardening temperatures, by quenching in different baths, on the tensile strength and elongation. These tests were made at the Watertown arsenal.

Specific Heat of Bath

The specific heat of the bath is an im-

portant factor, as the more rapid the cooling from 1650 to 200 degrees F., the more effective will be the hardening process. These are the temperatures at which the transformation which corresponds to the hardening process begins and ends.

A bath that consists of a liquid which volatilizes easily at the highest temperature it reaches from plunging the metal into it, forms a space filled with vapor around the steel which retards the further cooling action of the liquid. The agitation of the bath will throw off these vapors as it brings the liquid in contact with the metal and tends to equalize the temperature. The agitation of the piece to be hardened will give better results than trusting to the volatility of the bath, as it is more energetic in distributing the vapors.

The viscosity of the bath has an influence on the phenomenon of convection, which is the principal means of the exchange of heat; the higher the viscosity the less its hardening effect.

The conductivity of the bath has its effect on the exchange of heat between the piece to be hardened and the bath; therefore the greater the conductivity the more quickly the metal cools.

As a rule little account is taken of the specific heat of the bath, but it is an important factor. As soon as the heated metal is plunged into the bath the liquid begins to heat. The number of calories necessary for raising the temperature of the liquid a certain number of degrees will be the greater the higher the specific heat. Thus the cooling of the metal will heat the bath less the higher the specific heat of the latter, and consequently a bath is the more active the higher its specific heat. The less rapidly the equilibrium is established between the hardening bath and the metal quenched in it, the more active will be the bath.

The specific heat of mercury is much less than that of water and the cooling of quenched steel is three times as rapid in water as in mercury. The hardening effect is therefore much lower than that of water, but surface cracks and fissures are not nearly as liable to occur.

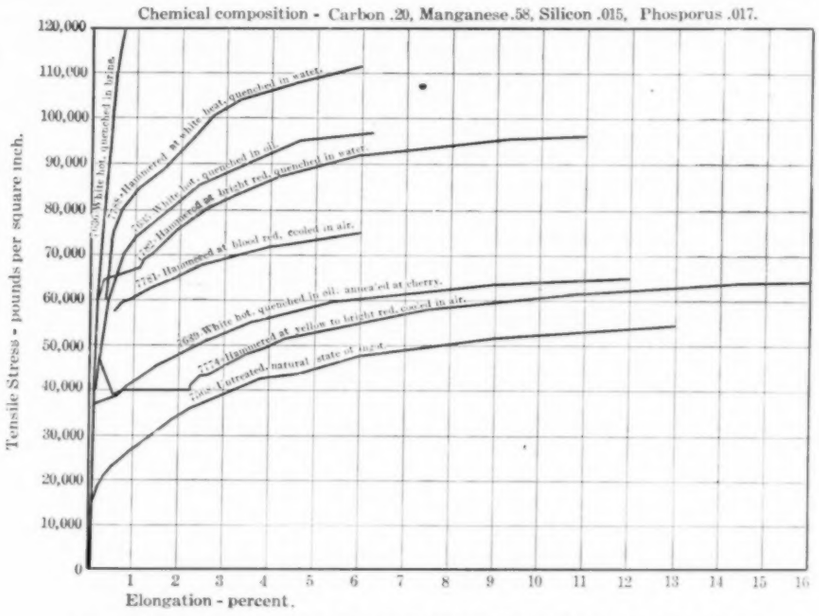

Chemical composition - Carbon .20, Manganese .58, Silicon .015, Phosporus .017.
Tensile Stress - pounds per square inch.
Elongation - percent.
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
7100 White hot, quenched in brine.
7250 Hammered at white heat, quenched in water.
7265 White hot, quenched in oil.
7295 Hammered at bright red, quenched in water.
7295 Hammered at blood red, cooled in air.
7785 Hammered at blood red, cooled in air.
7640 White hot, quenched in oil, annealed at cherry.
7775 Hammered at yellow to bright red, cooled in air.
7360 Untreated, natural state of ingot.

CHART 7. EFFECT OF HEAT AND MECHANICAL TREATMENT, ON THE TENSILE STRESS AND ELONGATION

Cracks and Fissures

Much serious trouble has been caused by cracks and fissures which have been produced by the abrupt cooling of steel. Many times a piece separates abruptly from the part quenched. The reason for this is easily given as during the cooling different parts of the steel are at different temperatures. This is many times caused by thick and thin sections in the same piece, but it also occurs in pieces of an even thickness, owing to the transformation in temperature not taking place everywhere at the same time. This causes internal strains which many times attain enormous value and result in the lessening and also stopping of the cohesive force which holds the molecules of the metal together. This causes brittleness and rupture at the places so affected.

In practical work the main thing to keep in mind is that these fissures only occur in high-carbon steel or some of the special alloys. There are several ways of overcoming this and the three which are the easiest to use and most certain in their results are as follows: When a water-quenching bath is used it may be covered with from ½ to 1 inch of oil, which will reduce the rate of cooling. A quenching bath of comparatively small size may be used, in which case the sudden cooling will be followed by a slight tempering effect, caused by the raise in temperature of the bath. The piece may be withdrawn from the bath before it is completely cooled. Uniform results are hard to obtain by this last method owing to the difficulty of judging the temperature at which the metal is withdrawn.

Warping

Warping may be caused by several factors, the two most important of which are not having the steel in a proper condition of repose before it is hardened and not putting the piece in the quenching bath properly. As any operation of working steel is liable to set up internal strains it is always best after rolling, forging or machining steel to thoroughly anneal the piece before hardening it. This allows the metal to assume its natural state of repose. In the machining operations the roughing cuts could be taken off, the piece annealed, then the finishing cuts could be given it and the piece hardened. This would also make the steel easier to machine as the metal is more uniform and in its softest state.

There are several rules that can be followed in hardening a piece of steel to prevent warping, and these rules always assume that the piece has been properly annealed before starting the hardening operations.

First, a piece should never be thrown into the bath, as by laying on the bottom it would be liable to cool faster on one side than the other and thus cause warping.

Second, the piece should be agitated in the bath to destroy the coating of vapor which might prevent its cooling rapidly, and also to allow the bath to convey its acquired heat to the atmosphere.

Third, work should be quenched in the direction of its principal axis of symmetry so that the liquid will cover the greatest possible surface at the instant of quenching. A gear wheel should be hardened perpendicular to its plane and a shaft vertically.

Fourth, hollow pieces, such as spindles should have the ends plugged, as they could not be quenched vertically on account of the steam which would be produced in the hole and which would throw hot water.

Fifth, pieces with thin and thick sections or of intricate shapes should be immersed in such a manner that the parts of greatest section enter first.

Sixth, to harden one part of a piece only it should be immersed so that it hardens well beneath the heated part.

Seventh, pieces which are very complicated should be rigged up with hoops, clamps or supports to prevent their warping.

Hardening Large Pieces

The hardening of large pieces gives somewhat different results as the transformation is not always complete, in

which case there is a partial return to the normal stable state, that is toward pearlite. Thus a small piece quenched from a high temperature in cold water is very hard and quite brittle, while a large piece quenched at the same temperature and under the same conditions is not quite as hard and only slightly brittle.

If the large piece is examined with the microscope it would indicate martensite to be present in the surface layer, while at a certain distance below the surface would be seen troostite and sorbite. This would show that the transformation was not as complete as in the small piece and would account for the lower degree of hardness and brittleness.

This might lead one to suspect that the constituents in the center of a large piece were the same as in annealed steel, as the coefficient of expansion and the electrical resistance seem to be the same.

From this might be drawn the conclusion that the mechanical properties of the two steels were not the same. These, however, are not the facts as the strengths and hardness are but little different from those of the small piece which showed martensite.

The principles and practices of hardening are practically the same for the special alloyed steels as for the ordinary carbon steels except that some of the alloying materials alter the point of transformation.

High-speed Steels

There is one notable exception to this, however, and that is in the case of high-speed or self-hardening steels. These steels are made by alloying tungsten and chromium or molybdenum and chromium with steel. These compositions completely revolutionize the points of transformation. Chromium which has a tendency to raise the critical temperature, when added to a tungsten steel, in the proportions of 1 or 2 per cent., reduces the critical temperature to below that of the atmosphere. Tungsten and molybdenum prolong the critical range of temperatures of the steel on slow cooling so that it begins at about 1300 degrees Fahrenheit and spreads out all the way down to 600 degrees.

These steels are heated to 1850 degrees for the molybdenum and 2200 degrees for the tungsten and cooled moderately fast, usually in an air blast, to give them the property known as "red-hardness." This treatment prevents the critical changes altogether and preserves the steel in the austenitic condition. The austenitic condition is one of hardness and toughness, and it is peculiar that under this heat treatment the steel is not transformed into the pearlitic condition.

One rule which has given good results in heat-treating these high-speed steels is to heat slowly to 1500 degrees Fahrenheit, then heat fast to 2200 degrees; after which cool rapidly in an air blast to 1550 degrees; then cool either rapidly or slowly to the temperature of the air.

Tempering Steel

Methods, Materials Used and Results Obtained

Negative quenching consists of cooling the metal through the critical zone at a rate equal to or below that which will give to the metal the greatest elongation when cold. This rate of cooling separates the mechanical results of quenching into the two distinct divisions mentioned farther back, namely, that for giving a cutting edge to tools and that for increasing the static strengths and dynamic qualities. It varies as an inverse function of the carbon content unless the elements used in the special alloys influence it.

Negative quenching gives a tensile strength and elastic limit about equal to that obtained in annealed steel and produces the highest possible elongation and a high reduction of area. This usually gives the steel the highest obtainable resistance to shocks.

As positive quenching becomes more and more pronounced it increases the tensile strength and elastic limit; at first slowly, then more and more rapidly, and reduces the elongation and resistance to shock in the same ratio. Thus by variations in the factors governing the activity of the quenching bath, any steel may be given its most suitable state for any given purpose. In fact all possible methods of quenching are but means of varying the rate of cooling, and the selection of the cooling mediums which will give the desired rate of cooling through each of the critical temperature zones of the metal in order to give it the desired properties is the real art of heat treatment.

Reducing the Hardness

Tempering steel, therefore, is to return it to a state of molecular equilibrium at atmospheric temperature by relieving any strains in the metal which have been caused by sudden quenching and correct any exaggeration of certain properties which have been caused by the hardening process.

The temperature to which a piece should be raised for tempering depends on the use to which it is to be put, the condition in which it has been left by quenching and the composition of the metal. The maximum temperature desired should only be maintained long enough to be sure that the piece is evenly heated.

The austenite which is retained in steel by the sudden cooling has a natural impulse to change into pearlite. Steels which have been reheated slightly after hardening give a freedom to the molecular change that will lessen the molecular rigidity set up by the hardening process. The higher the temperature is carried in reheating, the more it will lessen this molecular rigidity and the more will the austenite give way to a pearlitic formation.

Steels heated to 150 degrees Fahrenheit will be slightly tempered, but if heated to the temperature at which the straw color is formed on a brightened surface by the appearance of an iron oxide, namely 450 degrees, a greater tempering will result and the temperature at which this oxide assumes a permanent blue color, namely 575 degrees, will effect a still greater tempering. Each increase in this temperature of reheating reduces the hardness and brittleness, reduces the tensile strength and elastic limit and increases the elongation as well as the resistance to shocks.

Temperatures for Tempering

Steels which require a great hardness so that a fine cutting edge can be given them, such as razors, are not exposed to shock, hence can have a marked degree of brittleness. A reheating to 450 degrees Fahrenheit for tempering will be the best condition that such steel can be given. Tools which have to withstand violent shocks such as cold chisels and still retain a good cutting edge should be reheated to 575 degrees to further remove some of the brittleness. This will lessen the hardness and consequently the cutting powers but is the lesser of the two evils. These two cases might be taken as the two extremes of temper desired in cutting tools.

	Tensile Strength Lb. per Sq. In.	Elastic Limit Lb. per Sq. In.	Elongation in 2 In. Per Cent.	Reduction of Area, Per Cent.
Annealed at 1475 degrees..	87,640	64,400	29	59
Hardened at 1650 degrees, oil tempered at varying quenching temperatures.	125,000	103,000	21	56
	127 800	110,100	20	58
	130,500	124,000	17	62
	138,000	127 500	18	65
	147,000	140,750	17	57
	212,000	200,000	12	51
	232,750	224,000	11	39

TABLE NO. 2

Steels which are used in the building of machinery, as a rule, have the temper drawn much more than this and the variation in temper is only limited by the work which the parts have to do, the composition of the metal and the different degrees of temper which steel can be given.

Leaf springs, such as carriage springs, are usually reheated to about 800 degrees Fahrenheit. Gears which are in constant mesh without any undue pressure will give the best results as to wear, strength and resistance to shocks if reheated to about 675 degrees. Crank-shafts on internal combustion engines have to withstand considerable torsion, vibrational strains and impact stresses and seem to

stand the work best when reheated to about 1000 degrees.

Charts 8 and 9 show the effect of the above heat treatment for springs on two kinds of steel which might be said to show the two extremes in deflection, fiber stress and their resultant permanent set. In Chart 8 the elastic limit was reached on the second test. This for the vanadium steels was 85,000 pounds, or 234,500 pounds fiber stress with a permanent set of 0.48 inch. In the carbon steels, it was 65,000, or 180,000 pounds fiber stress with a permanent set of 1.12 inches. The carbon steel took an additional set of 0.26 inch on the third test and broke on the fourth in the center. The third test was repeated three times on the vanadium steel without any change in recorded lights. The tests were made by the American Vanadium Company.

The rate of cooling after reheating to the proper degree for tempering is immaterial, as when we reheat a piece, say to 400 degrees, we have changed the constituents of the metal all that we can without increasing this temperature. Thus a piece might be held at this 400 degrees for an hour and the change would be no more than that made in the first few seconds, as no change will take place during the cooling.

The changes which can be made in the strengths of steel are very forcibly shown in the following Table No. 2, which explains itself:

Tempering Equipment

The furnaces used are practically the same as those used in hardening, and furnaces which will permit of maintaining a constant temperature with appliances for measuring the heat so the correct temperature can be attained are the best kind.

Lead baths are used a great deal as it is easy to heat these to a certain temperature and hold them at a constant temperature for any length of time. With this the bath is heated to the temperature at which the steel needs to be tempered or drawn, the piece is placed in the bath and allowed to remain until it has attained the temperature of the bath, when it is taken out and cooled.

Salt baths are sometimes used where the drawing temperature desired is 575 degrees Fahrenheit. Salt fuses at this point and a certainty of obtaining this temperature in the steel is assured. In using this the salt is heated to 700 or 750 degrees and the steel placed in the bath. When this is done the cold metal will cause the salt which surrounds it to solidify and plainly show a white crust around it. When the steel has attained a temperature of 575 degrees the white crust will disappear as the salt which made it has melted and mixed with the rest of the bath. This clearly shows that it is time to take the piece out of the bath and allow it to cool.

This method can be used for tempering above 575 degrees and below 900 degrees, but is not practical for higher or lower temperatures owing to the alteration in the salt of which it is composed.

The gas, oil and electric furnaces described in the first section of Part 3 as well as some of the baths given there, are also used in tempering and any form of furnace or bath that will give the correct temperatures desired can be used with complete satisfaction.

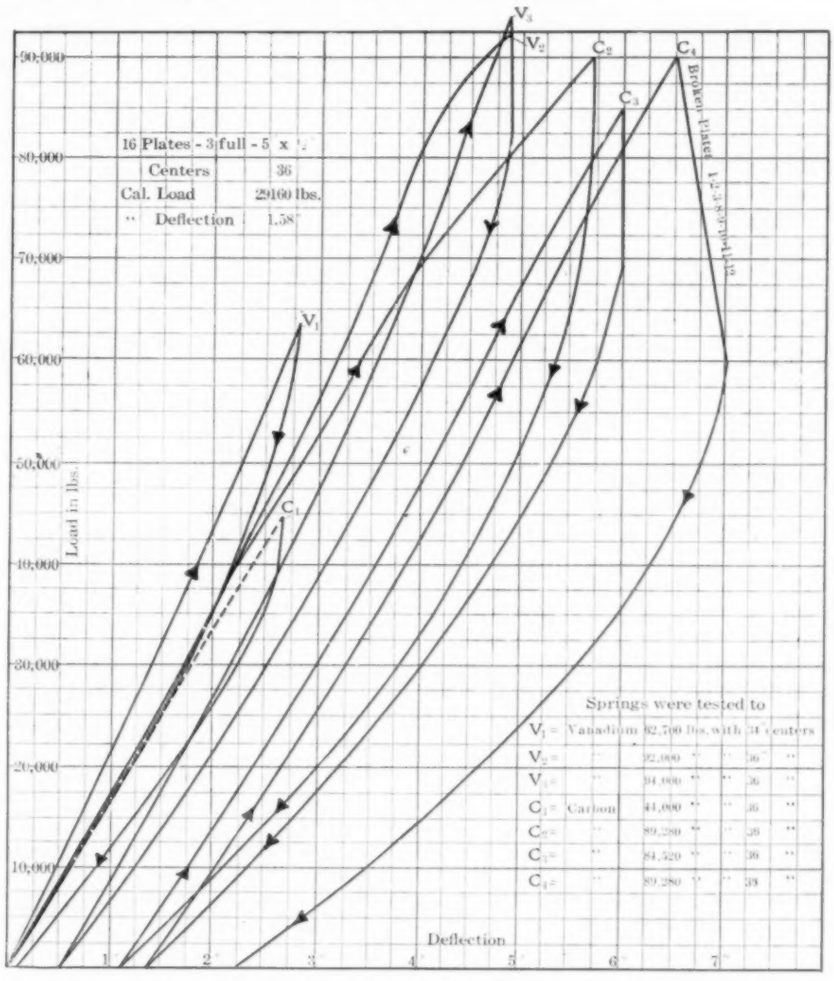


CHART 8. SPRING DEFLECTIONS. COMPARATIVE TESTS

Carbonizing

Methods and Materials Used—Effect of Alloying Materials and Heat Treatment

Many of the steels which give very high figures in their strength tests, are made hard enough to resist wear for such parts of machinery as gears, cams, ball races, etc., by hardening and tempering; but when the proper degree of hardness is obtained to reduce wear to a minimum, they are too brittle to withstand shock strains.

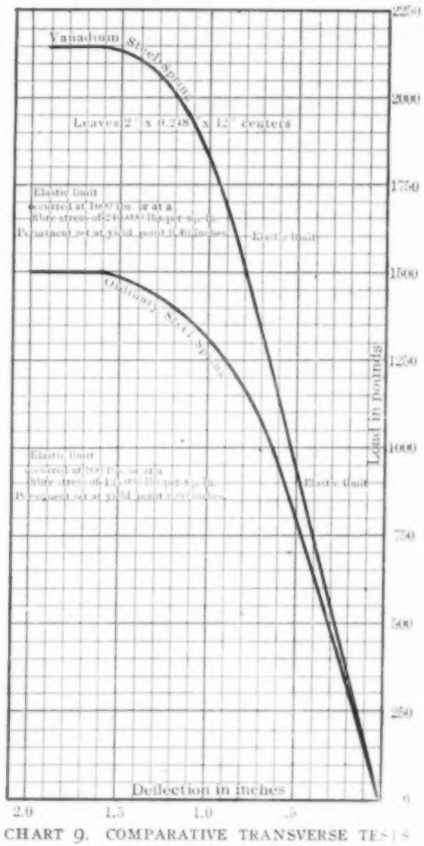


CHART 9. COMPARATIVE TRANSVERSE TESTS

For this reason case-hardening, carbonizing, or as it is called in Europe, "cementation," is resorted to, as by this process the outer shell can be made hard

enough to resist wear and the core of the piece can be left soft enough to withstand the shock strains to which it is subjected. By this method gears can be made from some of the special alloyed steels that will reduce the wear to a point that would have been considered impossible a few years ago, and at the same time resist shock to such an extent that it is very difficult to break out a tooth with a sledge hammer.

Several methods different from the old established one of packing the metal in a box filled with some carbonizing material and then subjecting it to heat, have been devised in the last few years. Among them might be mentioned the Harveyizing process which is especially applicable to armor plate. This in turn has been followed by an electrical process which claims to be a great improvement over the Harveyizing process. Very recently another process has been invented which uses gas for carbonizing in a specially constructed furnace. This is very useful for carbonizing small work.

Harveyizing and Electrical

The Harveyizing process uses a bed of charcoal over the work, the plates being pressed up against it in a pit or furnace and gas turned on so that the steel will be heated through the charcoal, thus allowing the carbon to soak in from the top.

This process has been a great success, but it also has its faults, as the carbon soaks in to a good depth in some places, while at other places, sometimes only a foot away, the carbon will not be so deep, so that when tested a shot will glance off from one spot and when it hits a short distance from this will tear a great hole in the plate. Then again the Harveyizing process has not been adaptable for small work.

Electricity has also been used in a like manner to the gas in the Harveyizing process. That is, armor plate has been covered with a layer of ground bone, the whole inclosed and a current of electricity turned on to heat the bone and metal so that the carbon will combine with the steel in a surface layer of varying depths, and it is claimed for this process that the depth can be regulated to any depth desired and the carbon is of an even depth over the entire surface.

As these two processes are only used on armor plate or other large work of a similar character and are at most too expensive in their installation to be made applicable to parts of machinery, or tools, they will not be gone into in detail here.

The Krupp process is similar to the above two in the kind of work it operates on, and differs from Harveyizing in that it uses a gaseous hydrocarbon to replace the bed of charcoal. This also is foreign to the subject, but the gas it uses is practically the same as that used in the furnace for carbonizing with gas which will be described later.

Factors Governing Carbonizing

The result of the carbonizing operation is determined by five factors, which are as follows: First, the nature of the steel; second, the nature of the carbonizing material; third, the temperature of the carbonizing furnace; fourth, the time the piece is submitted to the carbonizing process; fifth, the heat treatment which follows carbonizing.

The nature of the steel has no influence on the speed of penetration of the carbon, but has an influence on the final result of the operation.

If steel is used that has a carbon content up to 0.56 per cent., the rate of penetration in carbonizing is constant; but the higher the carbon content is, in the core, the more brittle it becomes by prolonged annealing after carbonizing. Therefore it is necessary that the carbon content should be low in the core, and for this reason a preference is given to steels containing from 0.12 to 0.15 per cent. of carbon for carbonizing or case-hardening purposes.

Some, however, prefer a steel containing from 0.20 to 0.22 per cent. carbon, owing to its being more easily worked with machine tools; but the results will not be as good as with a steel containing a maximum of 0.15 per cent. carbon. Greater strength and easier working qualities can be obtained by the addition of such alloys as chromium, vanadium, nickel, etc.

Effect of Manganese and Chromium

It is also very important that the manganese content of carbonizing steels be kept low. This should never exceed 0.35 per cent., as manganese has a tendency to render the hardened and carbonized surface brittle, thus making it liable to chip and break at the least shock.

Thus manganese is usually kept down to 0.20 per cent. and seldom exceeds 0.25 per cent.

While chromium has a tendency to produce a brittle hardness in steel, it prevents the development of the crystalline structure under heat treatment, thus refining the grain and making it better able to withstand shocks. Therefore chromium added in small percentages makes steels for carbonizing more homogeneous and imparts to them greater strengths and wearing qualities. Chromium, however, produces steels that are very difficult to machine; it is therefore combined with other ingredients which offset this, except for such uses as armor plate.

Vanadium used in homeopathic doses overcomes this difficulty of machining chrome steels to such an extent that it is claimed that a steel containing 1 per cent. chromium and from 0.16 to 0.18 per cent. vanadium can be forged and machined as easily as a 0.40 per cent. carbon steel.

Vanadium also produces high dynamic strengths, which gives the core of carbonized steels a high resistance to shocks

Effect of Nickel

Nickel added to ordinary carbonizing steel in comparatively small percentages obviates the brittleness which is usually produced by carbonizing and makes it more homogeneous, the pearlite being distributed much better. With 2 per cent. of nickel the steel is increased in strength; in some cases this strength is nearly double that of the ordinary carbonizing steel, but 2 per cent. nickel steel means nothing unless the carbon is of the proper percentages. When it is, it makes one of the best steels, when carbonized and tempered, for such parts as shafts, ball races, gears, etc. It should therefore be used wherever the 2½ cents difference in price does not make it prohibitive, except where the higher-priced alloy steels are demanded, owing to their greater strength and wearing qualities.

A 2-per cent. nickel steel carbonized so that the surface layer contains about 1 per cent. of carbon will be pearlitic, but a 7-per cent. nickel steel will show a surface layer that is martensitic, with a pearlitic core. Martensite being a constituent of quenched steel, a 7-per cent. nickel steel carbonized so the surface layer contains 1 per cent. of carbon, has the same constitution as an ordinary carbonizing steel which has been carbonized and hardened, that is, a pearlitic core and a martensitic outer shell. This martensite should become denser and denser as it approaches the outer surface.

If this 7-per cent. nickel steel is carbonized to a greater depth, so that the surface layer will contain 1.5 per cent of carbon, the core will be pearlitic and resist shock to a great degree. A martensite layer will be next to the core and close to the outer layer. This will give high strengths and the outer layer will readily polish without wear, thus giving it valuable wearing qualities.

This simplifies the processes of carbonizing, owing to its doing away with the hardening processes afterward, but the carbonizing and the cooling afterward must be carefully done in order to get good results from this process.

If, however, the proper carbonizing materials are used, the heat of the furnace regulated so that it remains steady and at the proper temperature, and the piece not cooled too quickly, a saving in time and expense can be made with this process of carbonizing, when this grade of steel is suitable.

Alloying Materials and Penetration

The influence of the different elements on the speed of penetration of the carbon, when carbonizing steels containing

the same amount of carbon and different percentages of manganese, chromium, nickel, tungsten, silicon, titanium, molybdenum and aluminum, is shown by Table 3.

PENETRATION OF CARBON PER HOUR

Component of Alloys.	Speed of Penetration Per Hr. in Inches.
0.5 per cent. manganese	0.043
1.0 per cent. manganese	0.047
1.0 per cent. chromium	0.039
2.0 per cent. chromium	0.043
2.0 per cent. nickel	0.028
5.0 per cent. nickel	0.020
0.5 per cent. tungsten	0.035
1.0 per cent. tungsten	0.036
2.0 per cent. tungsten	0.047
0.5 per cent. silicon	0.024
1.0 per cent. silicon	0.020
2.0 per cent. silicon	0.016
5.0 per cent. silicon	0.000
1.0 per cent. titanium	0.032
2.0 per cent. titanium	0.028
1.0 per cent. molybdenum	0.036
2.0 per cent. molybdenum	0.043
1.0 per cent. aluminum	0.016
3.0 per cent. aluminum	0.008

TABLE 3

The rate of penetration for ordinary carbonizing steel under the same conditions would have been 0.035 inch. Thus it will be seen that manganese, chromium, tungsten and molybdenum increase the rate of penetration. These seem to exist in the state of a double carbide and release a part of the cementite iron.

Nickel, silicon, titanium and aluminum retard the rate of penetration—5 per cent. of silicon reducing it to zero—and these exist in the state of solution in the iron.

As a general rule the alloyed steels which give the best results in annealing, hardening and tempering are not the best for carbonizing; for this reason most of these alloyed steels are made in a special grade for carbonizing. As an illustration of this, vanadium steel that gives the best results for crank-shafts, transmission shafts, connecting-rods and other moving engine parts is composed of 0.25 to 0.30 per cent. carbon, 0.40 to 0.50 per cent. manganese, 1 per cent. chromium and 0.16 to 0.18 per cent. vanadium, while the best carbonizing steel has from 0.12 to 0.15 per cent. carbon, 0.20 per cent. manganese, 0.30 per cent. chromium and 0.12 per cent. vanadium.

The Carbonizing Materials

The nature of the carbonizing materials has an influence on the speed of penetration and it is very essential that the materials be of a known chemical composition as this is the only way to obtain like results on the same steel at all times.

These materials or cements are manufactured in many special and patented preparations. The following materials are used and compounded in these preparations, but many of them give as good results when used alone as when compounded with others in varying percentages: Powdered bone; wood charcoal; charred sugar; charred leather; cyanide of potassium; ferro-cyanide of potassium; bichromate of potassium; animal black, acid cleaned. Prussiate of potash, anthracite, mixture of barium carbonate, graphite, petroleum gas, acetylene, horn, etc. Some have used illuminating gas and gasolene, but these act by dissociation and are not definite or positive enough for good results.

Such materials as bone and leather should not be used alone or in combination, as it is impossible to obtain definite results from them, owing to the changeability of their chemical composition when subjected to a temperature high enough for carbonizing.

How Wood Charcoal Acts

Wood charcoal is very largely used in carbonizing steels, but the value of this material varies with the wood used, the method employed in making the charcoal, and other factors. Used alone it gives the normal rate of penetration for the first hour, but after that the rate gradually decreases until at eight hours it gives the lowest rate of penetration of any of the carbonizing materials.

The best wood charcoal is that made from hickory. This is due to the fact that wood charcoal contains a percentage of carbonate of potassium, and this, in conjunction with the charcoal and the nitrogen of the air, in the carbonizing case, is capable of giving cyanide of potassium. Thus, by combining wood charcoal and carbonate of potassium, an increase in the rate of penetration can be obtained; but this speed decreases with time, and the exhaustion of the cement is due to the volatilization of the alkaline cyanides. If a current of ammonia is used, the rate of penetration becomes constant, as cyanide of ammonium is formed, and this is the one and only cement. Therefore the best carbonizing materials are the ones that produce the most of this element.

Powdered charcoal and bone give good results as a carbonizing material and are successfully used in carbonizing nickel-chrome steel by packing in a cast-iron pot and keeping at a temperature of about 2000 degrees Fahrenheit for four hours, and then cooling slowly before taking out of the pot or uncovering.

Action of Pure Carbon

Pure carbon, such as that of sugar, does not carbonize in vacuum; therefore a carbonizing material that is simply composed of carbon cannot act directly, but acts simply by dissolution of the carbon, starting with the iron in contact with it. Thus sugar should be mixed with some other material that will overcome this, in order to obtain the best results from carbonization.

Carbonic oxide, giving $2CO = C + CO_2$, which is formed by the action of the air, in the carbonizing box, on a carbonizing material that is composed simply of carbon, may act; but its action is slow and the carbonic acid, CO_2, has a decarbonizing action. This is the action which sugar, animal black (acid cleaned), etc., have.

Materials containing a cyanide act by means of the cyanogen radical $(CN)^1$. This compound is decomposed and replaces the carbon; it is in this manner that cyanide of potassium acts. The product is capable of producing cyanide, which is the case with a large number of cements.

Classifying Carbonizing Material

Ferro-cyanide of potassium gives cyanide, cyanate of potassium and oxide of iron. The mixture of ferro-cyanide and bichromate of potash gives rise to a new mixture of cyanogen and cyanate diluted in a mass of iron and chromium oxide. This mixture and carbonate of barium are subjected to the same conditions. In fact, the mixture, in the presence of the nitrogen of the air, gives rise to cyanide of barium according to the following equation: $2N + 4C + CO_3Ba = (CN)_2Ba + 3CO$. Therefore it acts by means of cyanide and carbonic oxide.

Certain carbonizing materials contain carbonates that are not dissociable at the temperature of carbonization, especially calcium carbonate. In the presence of carbon there is formed carbonic oxide, which carbonizes very slowly.

Classifying Carbonizing Material

Therefore the carbonizing materials might be classed as follows: First, cements which act by means of carbonic oxide; second, cements which act by means of a cyanide, such as potassium, barium or ammonium; third, cements which act by means of hydrocarbons.

To carbonize with the hydrocarbons, it is necessary to generate the gases in a tank out of such materials as will form cyanide of ammonium and conduct this to the receptacle in which the work has been placed in such a manner that it will soak into the pieces before passing out of the vent.

Temperature in Degrees Fahrenheit.	Materials Used and Rate of Penetration in Inches.			
	Charcoal 60 per cent., 40 per cent. of Carbonate of Barium.	Ferro-cyanide 66 per cent., 34 per cent. of Bichromate.	Ferro-cyanide Alone.	Powdered Wood Charcoal Alone.
1300	.....	.....	.....	.....
1475	0.020	0.033	0.020	0.020
1650	0.088	0.069	0.079	0.048
1825	0.128	0.128	0.128	0.098
2000	0.177	0.177	0.198	0.138

TABLE 4.

The speed of penetration caused by the action of different cements at different temperatures for the same time, i.e., eight hours is best shown by Table 4.

The nature of the carbonizing materials has a very pronounced effect on the rate of carbonization, or the percentage of the carbon content in the surface layer of the piece, or both.

Another Test of Penetration

At the same temperature, i.e., 1825 degrees Fahrenheit, for different lengths of time and with different cements, the rate of penetration obtained was according to Table 5.

Length of Time in Hours.	Materials Used and Rate of Penetration in Inches.				
	Carbon 60 per cent. + 40 per cent. of Carbonate.	Ferro-cyanide 66 per cent. + 34 per cent. of Bichromate.	Powdered Wood Charcoal Alone.	Charcoal and Carbonate of Potassium.	Unwashed Animal Black.
1	0.031	0.033	0.028	0.059	0.035
2	0.039	0.037	0.053	0.078	0.059
4	0.047	0.049	0.063	0.094	0.088
6	0.078	0.074	0.072	0.011	0.106
8	0.118	0.128	0.098	0.138	0.128

TABLE 5.

Eighty per cent. charcoal + 20 per cent. carbonate of barium, 40 per cent. charcoal + 60 per cent. carbonate of barium, ferro-cyanide alone and 66 per cent. ferro-cyanide + 34 per cent. bichromate were used with practically the same results for eight hours' time.

Another set of tests was carried out for a longer period of time, with other materials and at a uniform temperature of 1650 degrees Fahrenheit with the results given in Table 6.

Length of Time in Hours.	Materials Used and Rate of Penetration in Inches.		
	Charred Leather.	Ground Wood Charcoal.	Barium Carbonate and Wood Charcoal.
2	0.045	0.028	0.055
4	0.062	0.042	0.087
8	0.080	0.062	0.111
12	0.110	0.070	0.125

TABLE 6.

The test bars in this table were 3 inches long and ¼ of an inch square. The chemical composition of the steel was as follows: Carbon 0.14 per cent., manganese 0.58, silicon 0.01, sulphur 0.08, and phosphorus 0.03.

These tables show that charcoal when used alone gives the slowest rate of penetration, but when combined with other materials the rate of penetration is the highest of any of the tests made. In some cases the rate of penetration of the combined materials nearly doubles that of the wood charcoal alone.

Nitrogen and Ammonia

The commonly used carbonizing materials all contain nitrogen in some form or other, and as the non-nitrogenous materials cost from one-tenth to one-twentieth of those containing nitrogen, some experiments were made with anthracite and coke. After carbonizing the same sized test pieces with these for four hours at 1650 degrees Fahrenheit, the penetration for the anthracite was 0.006 inch and with the best grade of hard coke it was 0.0064 inch. Charred leather under the same conditions gave a penetration of 0.062 inch.

This would lead to the conclusion that nitrogen performs an important part in carbonizing.

The effect of ammonia was also tried by carbonizing in a gas pipe and packing the work in sugar charcoal as the non-nitrogenous material. Dry ammonia was passed into one end of the gas pipe and allowed to flow out through a small vent hole in the other end. The results obtained by carbonizing for four hours at 1650 degrees were 0.058 inch for the charred sugar alone, and 0.070 inch for the charred sugar which had ammonia passing through it.

The non-ammonia specimen was bluish-black in color and when sawed appeared soft, while the ammonia-treated specimen was of a distinct whitish luster and appeared to have a tough outer skin when sawed.

Thus while all the evidence goes to prove that nitrogen aids carbonizing in practical work, its action is not yet quite clear. Ammonia, on the other hand, is absorbed by the iron and becomes the prime agent in any change, thus causing an increase in the rate of carbonization.

Effect of Temperature

The degree of carburization of the skin depends largely on the degree of temperature maintained during the carbonizing process; therefore it is necessary that the temperature be kept at a definite point in the carbonizing of steels. This can best be done by attaching to the furnace something to gage the heat, such as a pyrometer.

If the temperature is too high, the metal is liable to crystallize and the core will rapidly become brittle.

The temperature to which the metal can be safely raised in carbonizing varies with the kind of steel used. As a general rule the ordinary carbonizing steel cannot be raised to a temperature in excess of 1800 degrees Fahrenheit. If the original carbon content is high, even this temperature cannot be safely reached, while with some of the alloy steels, such, for instance, as nickel-chrome steel, a carbonizing temperature of 2000 degrees can be retained for four hours without the core crystallizing, and the rate of penetration will be reasonably high, providing, of course, that the original carbon content is low.

The temperature, however, must be kept above 1300 degrees Fahrenheit, as ordinarily carbonization cannot take place below that point, although in an experimental way steel has been carbonized at about 850 degrees by using a mixture of cyanide of potassium, chlorides of the alkalies, and the alkaline earths, the latter being used to lower the fusion point of the cyanide.

The percentage of carbon which is absorbed by the steel is also affected by the temperature as well as by the materials used.

With a given depth of penetration and a given amount of carbon in the carbonizing material, steel will absorb a greater percentage of carbon at a high temperature than at a low one.

Heat Treatment After Carbonizing

The heat treatment following carbonizing should be very carefully done, owing to the fact that the piece must have a very hard outer surface to resist wear and a non-brittle core that will resist strains; also, some methods of heat-treating have a decarbonizing effect, and some of the steels have a tendency to produce cracks or fissures and to warp. Thus crank-shafts for internal-combustion engines were formerly carbonized and hardened, but owing to the difficulty of preventing cracks and warping, this practice has been abandoned.

As a general rule the piece should be annealed after carburizing. This can best be done by leaving it packed in the carbonizing case, with the cover fastened on, and allowing it to cool gradually; but if the carbonizing temperature is not over 1600 degrees Fahrenheit, it can be allowed to cool to 750 degrees, then reheated to 1400 degrees and quenched with good results.

If the carbonizing temperature is a high one, i.e., above 1800 degrees, the piece should be allowed to cool, then reheated to 1650 degrees, and quenched and reheated again to 1400 degrees and quenched

The reason for the double quenching is that the piece must be heated to above its point of transformation, i.e., 1650 degrees, to destroy the crystallization and consequent brittleness, which is liable to be in the core when it is carbonized at a high temperature; but this leaves the carbonated surface layer not hard enough to resist wear, therefore it must be quenched again at 1400 degrees.

This point of transformation varies with the different components of the high grade alloy steels, and this should be ascertained before hardening the piece.

By quenching directly from the carbonizing retort a distinct line is formed between the high-carbon outer shell and the low-carbon cone and this is liable to cause the metal to crack on this line when the work is used for parts similar to rollers in roller bearings, owing to the wearing and crushing strains to which they are submitted, but if the work is properly heat treated after carbonizing, this distinct line

is made to disappear, and the danger of the steels cracking there is removed.

Time of Exposure

The time which the work is submitted to carbonizing is an important factor, as by the regulation of this under a given constant temperature is what gives the depth of carbon desired, and by the proper depth of the carbon is obtained the percentage of carbon desired in the surface layer.

The percentage of carbon in a carbonized piece of steel gradually reduces from the outer shell to the core. The lower the carbonizing temperature, the less the time of submission to the carbonizing temperature, and the smaller the percentage of carbon in the carbonizing material the greater will be this reduction.

A round bar of steel which was carbonized to the depth of 3/16 of an inch was examined by turning off 1/16 of an inch, and analyzing the turnings for carbon, then another sixteenth was turned off and analyzed and the third and fourth sixteenth treated in a like manner. This gave a carbon content of 1.24 per cent. for the 1/16 of an inch taken from the outside, the second sixteenth gave 0.85 per cent. carbon, the third sixteenth showed 0.24 per cent. carbon and the fourth or core contained 0.13 per cent.

The time of submission required for a certain depth varies with the kind of carbonizing materials as well as with the process used.

The carbonizing materials, such as powdered bone, charcoal, etc., which require that the work be packed in an iron box or other receptacle, take considerable more time to carbonize the work than when gases are used to furnish the carbon, owing to the necessity of the heat penetrating the box and carbonizing materials before it can affect the work.

In case a deep penetration of the carbon is required, and the carbon in the carbonizing materials is nearly or entirely absorbed, it is a difficult operation to insert fresh materials in the packing box.

Another point might be mentioned here and that is that all steels do not retain their carbonization. One specimen was examined by taking a very thin cut from the outer surface for a part of its length which on analysis showed 1.25 per cent. of carbon. The piece was then laid aside for six months, and a similar cut taken from the rest of its length, which on analyzing showed only 0.92 per cent. of carbon. This showed that the carbon dissolved little by little into the mass.

Carbonizing With Gas

In the use of hydrocarbons, or gases, a fresh supply can be kept flowing into the carbonizing receptacle and the time greatly reduced for deep penetration with an appreciable reduction of time for the shallow penetrations.

A very important factor in carbonizing with gas is the furnace, as on the design and operation of this to a large extent depends the success or failure of the process.

In Fig. 22 is seen a drawing on the center line of the furnace for carbonizing with gas, which is built by the American Gas Furnace Company, of Elizabeth, N. J., which holds patents covering it, while Fig. 23 is an outside view of the same.

In Fig. 22, *A* is the retort in which the work is placed. This is made out of extra heavy 8-inch pipe for the size of furnace shown and is made to revolve on the rollers *B* by the gear wheel *C* and the worm *D*, which in turn is propelled by the sprocket wheel shown in Fig. 23. *E E* are air compartments to prevent the heat and work from getting into that part of the retort which extends beyond the heating furnace; *F* is the heating-gas-chamber, the gas coming in through 5 openings or burners similar to the one shown at *G* and exhausting out through others; *H* is the cover for the end of the retort and is fastened on with hinged bolts and thumb screws. This is taken off in order to put the work in the retort, the partition *I* and carbonizing gas outlet *J* coming with it.

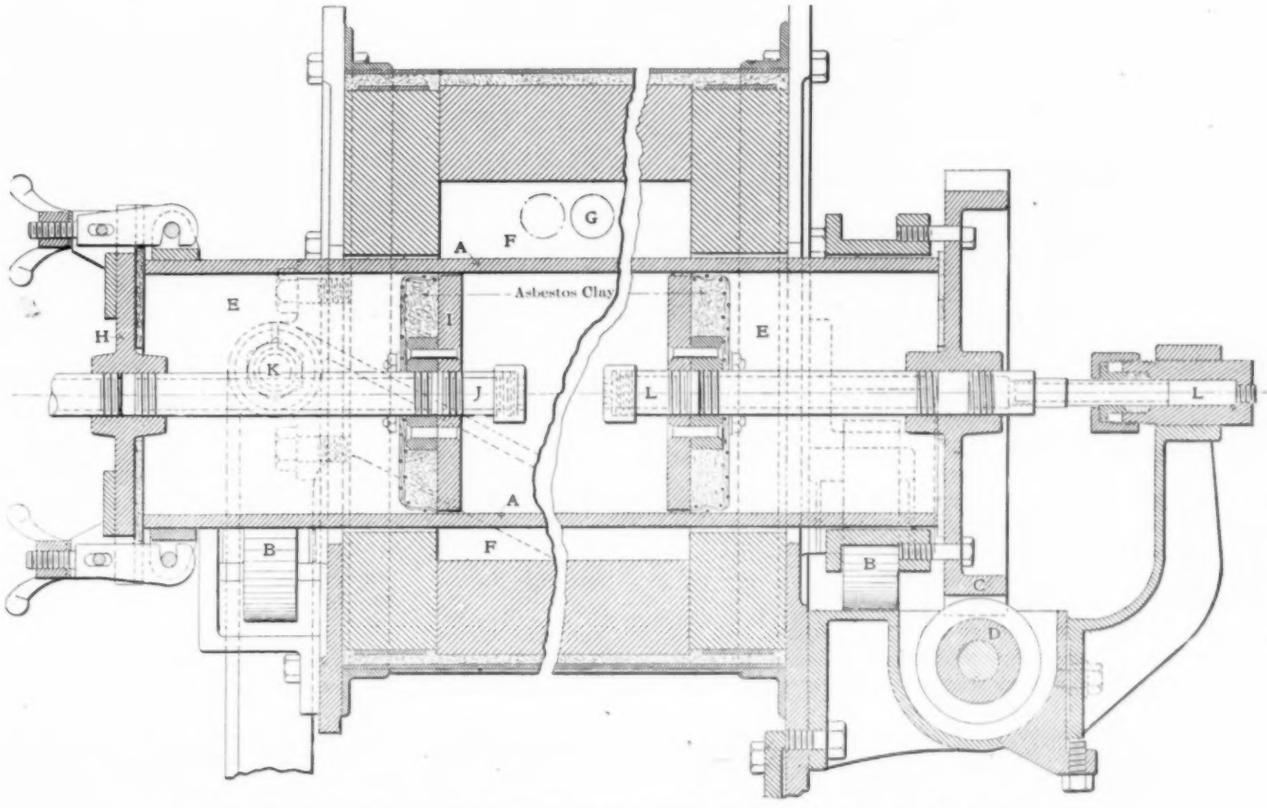


FIG. 22. SECTIONAL VIEW OF AMERICAN GAS FURNACE COMPANY'S CARBONIZING FURNACE

Operation of Furnace

The heating gas is fed through pipes and burners on the side and the carbonizing gas passes through the hose shown in Fig. 23 and the pipe in the center of the retort at *L*, Fig. 22, then into that part of the retort where the work is held. After

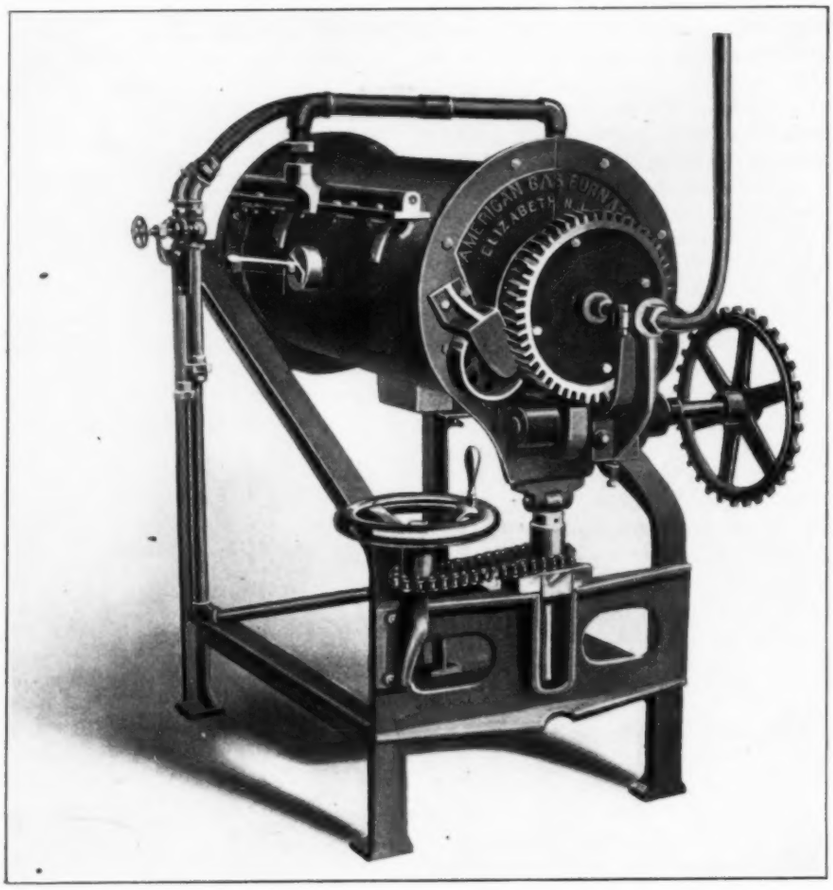


FIG. 23. VIEW SHOWING REVOLVING AND TILTING MECHANISM

the carbon has penetrated the metal the gas escapes through the outlet *J*.

This method of operating has many advantages over that of packing the materials in an iron box with bone, charcoal, etc., as the carbon in the retort is held constant by the steady flow of the gas; the work can be inspected for heat temperature by shutting off the carbonizing gas and looking through the outlet pipe *J*, where the work can be seen and its color noted; the carbonizing gas does not need to be turned on and used until the work has attained a temperature that will absorb the carbon and it can be shut off the minute the pieces to be carbonized have attained the proper depth of carbonization.

The carbonizing gases are formed of liquids which are put into a generator.

Starting with a cold furnace in the morning, an hour and a half is usually required to get the work hot enough to absorb the carbon, after which 40 minutes is required to attain the proper temperature when new work is put in the retort. As no packing of the metal and materials in iron boxes is required, this effects a great saving in time and the work can be carbonized at a greatly reduced cost.

Pyrometers can be attached to the furnace to gage the heat for the correct temperatures, and when this has been attained the valves and cocks can be set so that the work can be duplicated for any number of times and the furnace run for a long period with an assurance of the quality of the work turned out, as the temperature is held constant.

As the work is made to revolve in the furnace, similar to the action obtained by a tumbling barrel, an even depth of carbon is obtained on all sides of the work and this overcomes, to a large extent, the tendency of carbonized pieces to have hard and soft spots, as the soft spots are usually caused by the piece coming in contact with something which would not allow the carbon to act on that spot.

Results From Carbonizing With Gas

Odd shaped and intricate pieces can be carbonized by this method that it would be difficult to do by packing in an iron box in such materials as bone and charcoal.

The difficult work done is probably best illustrated by the piece shown in Fig. 24. This piece has been broken open to show

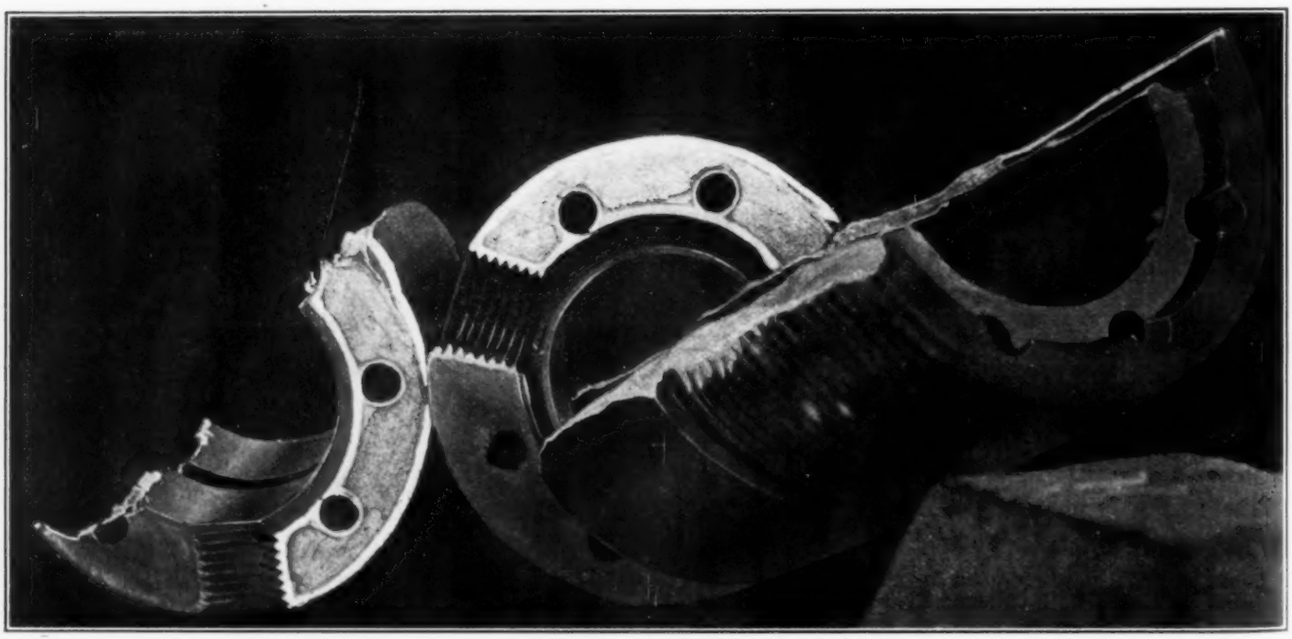


FIG. 24. CARBONIZED WITH GAS BY THE AMERICAN METAL TREATMENT COMPANY

the action of the carbonizing gas on the seven small holes around its rim, and it will be seen by a glance at the half-tone that the carbon penetrated to a good depth all around these holes; it being shown at a distance of about 4 inches from the end to the right of Fig. 24, which is where it was broken for inspection. It also showed that the carbon had a good even penetration as to depth on all of its exposed surfaces both inside and outside.

Some Results of Time

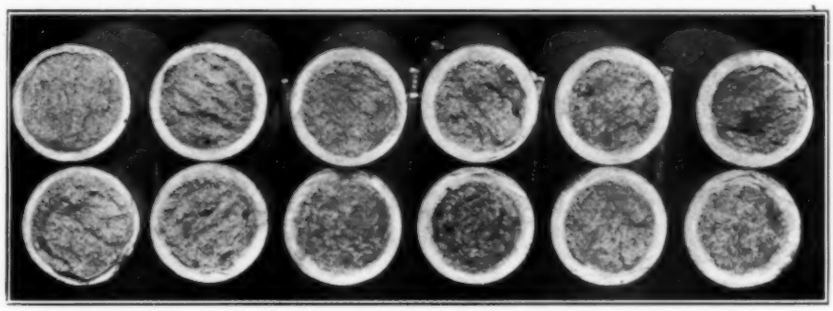
The results of different lengths of time that the work is submitted to carbonization in this gas furnace is shown in Figs. 25 and 26.

The set of test pieces in Fig. 26 shows the depth of penetration for each hour from 1 to 9 inclusive as follows, as well as the size and shape of the piece:

Time. Hours.	Size of Test Piece.	Depth in Inches.
1	⅜ in. round.	.015
2	⅜ in. round.	.020
3	⅜ in. round.	.030
4	⅜ in. round.	.038
5	⅜ in. round.	.046
6	⅜ in. round.	.053
7	⅜ in. round.	.056
8	⅜ in. round.	.058
9	⅜ in. round.	.060
9	⅜ in. round.	.063
9	⅜ in. square.	.075

Odd-shaped Pieces

Intricate or peculiar-shaped pieces which would not turn over in the furnace, but would slide around on the bottom, would have very little carbon on the side which remained in contact with the retort, and for these it would be necessary to put something inside of the furnace so constructed that it would cause them to turn over. Delicate pieces which would be liable to break would also have to have some special apparatus inside of the retort to protect them.



1 Hour 8 Hours 10 Hours 12 Hours 14 Hours 16 Hours

Time for Carbonizing

FIG. 25. QUENCHED DIRECTLY FROM THE CARBONIZING FURNACE

The distinct line between the carbonized shell and the core is obtained by plunging the metal directly from the carbonizing furnace into a quenching bath.

By Fig. 25 is shown the depth of the carbonized shell that is obtained in this furnace by carbonizing for 4, 8, 10, 12, 14 and 16 hours and then quenching in a lard-oil bath directly from the furnace.

The test bars shown in Fig. 25 were ⅝ inch in diameter and are reproduced here at about their actual size. The results as to depths for this set of pieces is as follows:

Time for Carbonizing in hours.	Depth of Penetration in inches.
4	0.040
8	0.062
10	0.071
12	0.079
14	0.085
16	0.090

The furnaces used for carbonizing with gas are designed specially for this purpose, and are, therefore, not practical for use as hardening, annealing, or tempering furnaces, although they might be made useful for annealing or hardening large quantities of work by being fitted with appliances for handling the same.

This makes the cost of installation higher than for the appliances used for carbonizing in the old way. The cost of carbonizing, however, is about one-half of that of the old method, which makes the furnace soon pay for itself by the saving in materials and labor.

Where the cost of carbonizing is reduced to this extent it makes it commercially practical to carbonize steel parts that were considered prohibitive by the high cost and non-uniform results of the old method.

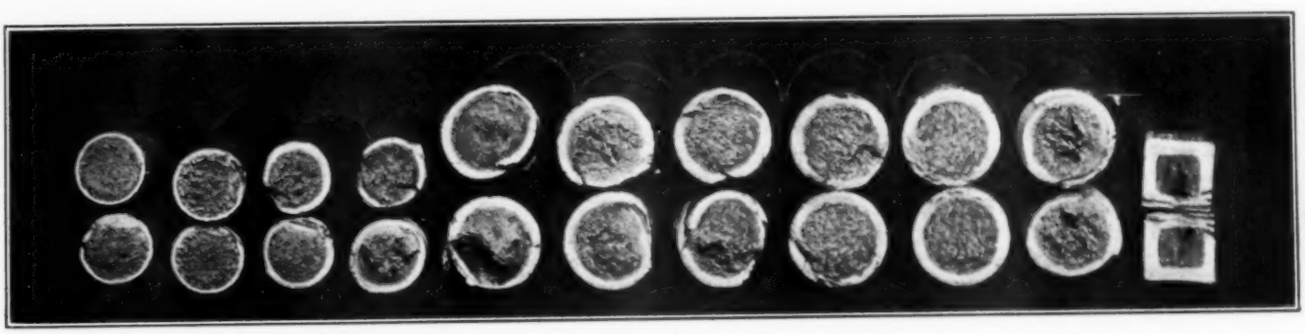
Non-uniform Results

Owing to the nature of the process of carbonizing by the old methods it is very difficult to obtain uniform results with pieces packed in the same box, or to repeat these results in other boxes.

In order to judge the temperature of the pieces packed in a box it is necessary to insert test wires through the cover. After a certain time a test wire near the outer edge of the box is withdrawn and the temperature is found to be just right for carbonizing, but if one is drawn out of the center of the box at the same time it will be seen that the temperature here has not risen high enough, as it takes a much longer time for the pieces in the center of the box to be raised to the proper temperature than for those near the outer surfaces of the box.

As the carbonizing material must be packed in the box with the pieces, this means that the pieces near the sides of the box will begin to absorb the carbon before those in the center, and, therefore, the penetration will be greater. As the percentage of carbon in the outer surface of the pieces being carbonized is greater the greater the depth of penetration, it also means that the pieces near the outside of the box will have a greater carbon content on their surface than the pieces in the center, and this also means that they will be harder.

Carbonizing with gas overcomes this to a large extent, if not entirely, as the carbonizing gas is not turned on until all of the pieces in the retort of the furnace have arrived at the proper carbonizing temperature, and it is shut off the minute the proper depth of carbonization has been obtained. The furnace can also be so regulated that the same results can be obtained with the next lot of pieces put in the retort.



1 Hour 2 Hours 3 Hours 4 Hours 5 Hours 6 Hours 7 Hours 8 Hours 9 Hours 9 Hours 9 Hours

FIG. 26. PENETRATION OF CARBON EACH HOUR FROM ONE TO NINE

Properties: Strength, Wearing Qualities, Etc.

Methods of Testing Steel for Strength, Strains, Hardness, Etc.; Results Obtained for Ordinary Carbon and Various Alloyed Steels

In designing machinery so that all parts will give the greatest wearing qualities, withstand the greatest shocks and carry the greatest loads for the smallest amount of material used, it is necessary to know what the qualities of the materials are in this regard. For this reason numerous methods and appliances have been devised to get the actual qualities of metals before putting them into machines, buildings, bridges, etc.

One of the first and most important of these is the tensile strength. This is found by taking a piece of material, usually of a definite size, and pulling it apart by gripping both ends and applying a steady strain, by pulling on one end, until it is broken. The load required to break the piece is the ultimate strength that it will stand. This is usually figured in the load in pounds which it takes to break a square inch cross-section of metal and is called by many the tensile strength. In calculating the ultimate tensile strength no account is taken of the lateral contraction or expansion of the piece.

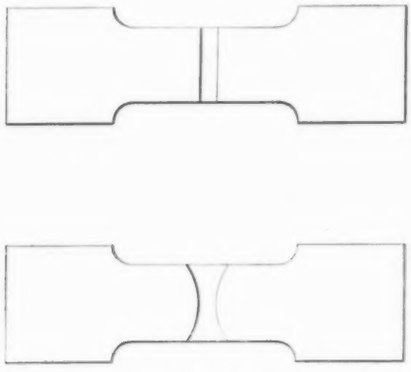


FIG. 27

In pulling a test bar an external force is acting which creates a resisting force within the body, this being merely another way of expressing Newton's third law of motion. This internal resistance is due to numerous small forces of attraction which are exerted between the molecules of the body.

In subjecting a test bar of steel to this pulling strain one naturally assumes that the stress is uniformly distributed over any cross-section of the bar, but this is not the case, as if two parallel lines are drawn near the breaking point and on opposite sides of it, it will be found that the tension applied causes the lines to become convex toward each other as shown by Fig. 27. This is caused by the metal stretching more on the outer surfaces than it does in the center. The harder the steel the less convex will these lines be to one another and in the hardest state in which the steel can be put, they are nearly parallel.

The tensile strength shows the ultimate load that a piece of steel will carry without breaking, if it is applied in the same direction in which the test is made.

Compression

The compression of a body is the opposite of the ultimate strength, as instead of pulling on the bar to get it to stretch and break, the load is applied in the opposite direction and the bar is pushed on, to see how much pressure can be applied before the metal will decrease in its dimensions and take a permanent set, at which point the elastic limit of compression would be obtained or the compression can be carried on to the point of rupturing the metal, which would be the ultimate strength of compression.

For the tensile strength and compression tests machines similar to that shown in Fig. 28 are used. This has a pulling capacity of 100,000 pounds and scribes the result on a recording chart which is shown in white on the cylinder near the top of the machine. The elongation is also scribed on this chart and the elastic limit is shown.

Chart 7 shows a reproduction of one that was taken on this machine. On this chart is recorded several different kinds of steel to show their relative properties. The test bar was 1-5 of a square inch, hence the tensile strength and elastic limit shown on the chart should be multiplied by 5.

Table 7 gives the results of these tests in the correct amounts as can be figured from the chart.

These machines are built in larger and smaller sizes and one has been built and is in use which has a capacity of 4,000,000 pounds. Test bars are of a special form which is smaller in the central portion than at the ends, as shown by Fig. 27, and they are usually round.

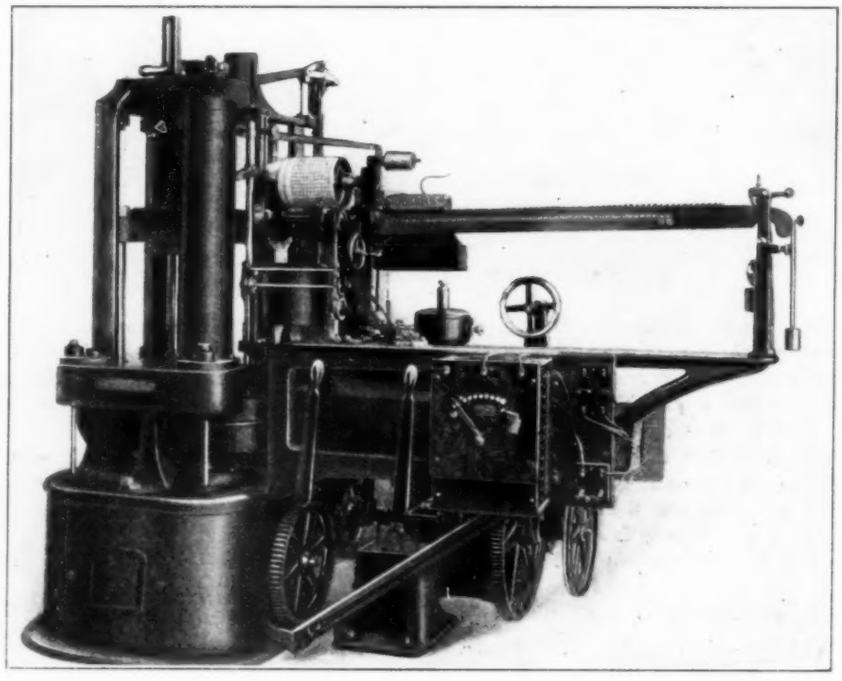


FIG. 28. MACHINE FOR PULLING TEST BARS

In testing steel by applying tension, the ratio of the unit stress to the unit of deformation is a constant up to a certain point, which is usually well defined. This deformation is shown in the stretching of the piece due to the stress imposed and is called the strain. As long as this strain or stretch disappears when the load is removed the metal may be called elastic. No solid, however, is perfectly elastic, as a slight permanent set takes place with the smallest strain. This is shown by the incline of the line from the bottom of Chart 7 to the elastic limit. As long as this permanent set is very small the body may be considered elastic for all practical purposes.

Elastic Limit

By increasing the stress we reach a point where a decided permanent set takes place and when the load is removed the piece will not go back to its original length but remains at the length it was when the load was on. This is the point at which the metal ceases to have the property of elasticity by a yielding of the cohesive forces which bind the molecules together, or in other words, the stress of the pull becomes greater than the cohesive force. This point is called the elastic limit and is shown on Chart 7 by the first sudden bend in the curves scribed thereon.

From the elastic limit to the limit of the metal's strength it might be that none of the strain or stretch will disappear on removing the load. The metal would then be considered plastic. If all of the molecular cohesive force is not destroyed we would find that a small part of the strain or stretch would be elastic while the greater part might take a permanent set. The metal would then be called ductile, and the ductile stage of wrought iron and steel is not reached until we pass the elastic limit.

Increasing the stress farther, past the elastic limit, makes the metal gradually lose its ductility until we reach the highest point of applied stress as shown at *A*, Chart 7, at which point all the stram or stretch becomes permanent and the metal is nearly perfectly plastic. At this point the tensile strength has been reached and it is indicated on the pulling machine shown in Fig. 28 by the dropping of the beam of the scale, if it has been balanced up to this point.

Specimen Tested.	Tensile Strength, in pounds per square inch.	Elastic Limit, in pounds per square inch.	Elongation, in 2 inches, per cent.	Reduction of Area, per cent.
Carbon steel for crank shafts	82,500	50,000	30	66
Nickel steel for crank shafts	116,000	90,000	22	71
Vanadium—chrome steel (crank shaft)	165,000	147,000	12	63
Vanadium—chrome steel (gear)	200,000	185,000	13	58
Vanadium steel	228,375	228,375		

TABLE 7. RESULTS OBTAINED FROM CHART 7.

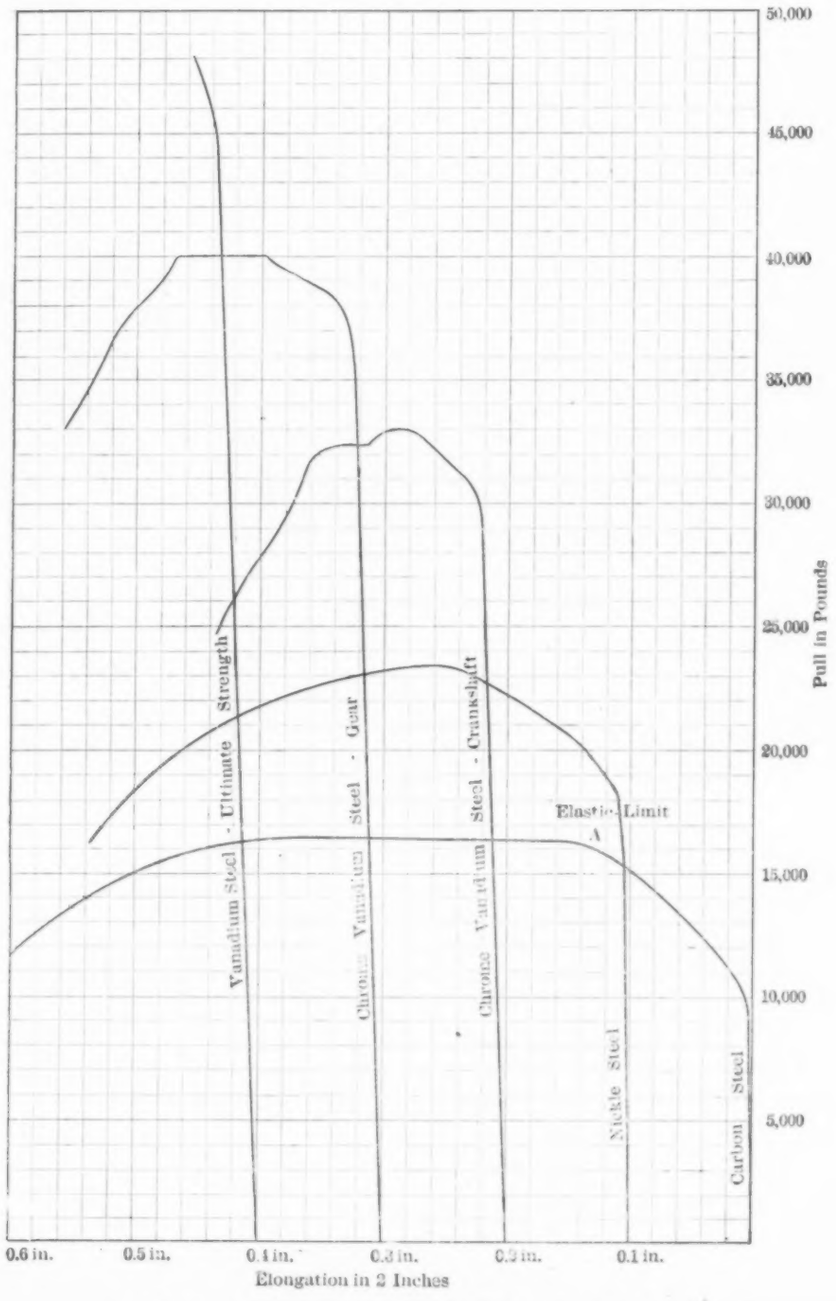


CHART 7. CHART TAKEN ON PULLING MACHINE SHOWN BY FIG. 28

Modules of Elasticity

The modulus of elasticity indicates the springiness or resilience of a body or, in other words, how much it will yield under any stress up to the elastic limit. This modulus of elasticity is obtained by dividing any stress up to the elastic limit by the strain produced per inch of its length. This is sometimes called the modulus of rigidity.

These modules of rigidity average about as follows for different metals:

Aluminum alloys	10 million.
Phosphor bronze	13 "
Manganese	15 "
Wrought iron	28 "
Mild open-hearth steel	28 "
Tool steel	29 "
Nickel steel	28 "
Nickel-chrome steel	30 "
Vanadium-chrome steel	30 "

Elongation

From the point *A* on, the strain of the metal increases as fast or faster than the stress, until final rupture is about to occur and the amount which the test bar has stretched at its breaking point over the original length is the percentage of elongation. As this stretching takes place in a fraction of the length it is necessary to know the original length of the test bar and the percentage it has elongated in that length, as the percentage in 2 inches would be much greater than that in 4, 6 or 8 inches.

Thus a statement of the percentage of elongation is worthless unless the original length of the test bar is given.

When there is little or no elongation the metal is very brittle and the greater the elongation the lower will be the de-

gree of brittleness. Thus steels which have been quenched from a high temperature show very little elongation and those which have been burned show almost none, while a thoroughly annealed piece of steel will show a high percentage of elongation.

This is well shown in Table 8 as well

FIG. 29

as in the other tables in this article where elongation is given.

The composition of the metal also has a great effect on these strengths, as was explained farther back in the effect of alloying materials. The metal used for the strengths obtained in this table was as follows: Carbon, 0.33 per cent.; nickel, 2.50 per cent.; manganese, 0.43 per cent.; silicon, 0.26 per cent.; phosphorus, 0.023 per cent., and sulphur, 0.032 per cent.

Reduction of Area

After the elastic limit has been reached the elongation sets in, and as the molecular cohesion has not ceased a reduction in the area takes place. In a round test bar this would mean a reduction in the diameter. This molecular cohesion causes the mass of the metal to flow and as the pulling increases the length, the area or in a round piece the diameter decreases in nearly a like proportion. While certain formulas may be adopted to figure the reduction from the elongation these only give approximate results, as the state the metal is in and the numerous alloying materials cause large variations in the rules laid down. The shape which the test bar usually takes in this reduction is shown by Fig. 29.

The percentage of the reduction of area is obtained by dividing the original area minus the area after fracture, by the original area.

For many years, and even today, in ordinary shop practice the tensile strength, or what the steel would stand in pulling apart and the elongation or the amount it would stretch under a given load, were all the tests which were given the metal as they were considered the all important. While these are very important tests it was discovered through many failures of steel that the metal might be very good in these tests and still fail miserably in practice.

This has led to the conclusions that the elastic limit should be brought up closer to the tensile strength and that the reduction of area is a truer measure of the molecular cohesion than the elongation. The molecular cohesion being the force which binds together the particles that go to make up the mass of the steel, when it weakens the metal is weakened and when it ceases in a given territory the metal fractures at that point or if it ceased throughout the mass the metal would deteriorate and crumble.

Steel might show a large elongation before final rupture, but this might be caused by a part of the cohesive force ceasing and the balance remaining constant. This would have the tendency to produce miniature fractures throughout the mass of the metal and increase its bulk. When the reduction of area, however, shows a large percentage with a small elongation, it means that the cohesive force has remained nearly constant. The greater the reduction of area in comparison with the elongation the greater cohesive force will be shown and consequently a greater homogeneity.

This lessening of the cohesive force has been given many names, such as "fatigue," "mysterious failure," etc., but the one which is the most applicable is "intermolecular deterioration," as it causes what this name implies.

Result of Ingredients on Strength

Carbon alters the strengths of steel in such a manner that one can almost lay down a definite rule as to its action. Pure iron has a tensile strength of 45,000 pounds per square inch and a compressive strength of 80,000 pounds.

If we start with pure steel at 40,000 pounds tensile strength per square inch, each 0.01 per cent. of carbon up to 0.9 will increase this 1000 pounds in acid open-hearth steel and 770 pounds in basic open-hearth. If the color method of judging the carbon is used, this should be increased to 1140 and 820 pounds respectively, as this method does not show all the carbon present. Bessemer steel would probably show a higher and crucible steel a lower value than this. As the heat treatment alters these strengths this rule can only be used approximately.

Table 9 shows the effect of different percentages of nickel in conjunction with a low-carbon steel on the strength.

Table 10 shows the effect of some alloying materials which are used in the highest grades of steel made.

Torsion

The resistance which a test bar gives to being twisted like a corkscrew is called its torsional strength.

This is best illustrated by Fig. 30, which gives the number of twists and the number of pounds which were applied to make these twists. This gives an indication of the ductility of different kinds of steel under this stress.

The parts of machinery for which this test is applicable are numerous, as this strain is given steel used for crankshafts of engines, line-shafts and numerous other parts which act as a transmitter of power. Some use this test to determine the shearing strength of metals, but it only gives this to a slight degree by showing the resistance of one cross-

Heat Treatment.	Tensile Strength in pounds per square inch.	Elastic Limit, in pounds per square inch.	Elongation in 2 Inches, per cent.	Reduction of Area, per cent.
Quenched from 1600° F.	225,000	208,000	4	19
Quenched from 1600° F. drawn at 600°.	215,000	201,000	6	14
Quenched from 1600° F. drawn at 800°.	190,000	150,000	9	20
Quenched from 1600° F. drawn at 1000°.	170,000	145,000	12	37
Quenched from 1600° F. drawn at 1200°.	155,000	125,000	14	38
Quenched from 1600° F. drawn at 14000°.	135,000	98,000	17	48
Quenched from 1600° F. drawn at 1600°.	104,000	65,000	24	51
Thoroughly annealed.	88,000	60,000	28	58

TABLE 8. STRENGTH OF STEEL AS EFFECTED BY HEAT TREATMENT.

Per Cent. of Nickel.	Tensile Strength, in pounds per square inch.	Elastic Limit, in pounds per square inch.	Elongation, in 4 inches, per cent.	Reduction of Area, per cent.	Heat Treatment.
1—1.5	78,000	48,000	18	35	Quenched from 1650 degrees F.
2.5—3.5	97,000	82,500	15	41	Quenched, drawn at 600 degrees.
2.5—3.5	85,000	60,000	18	48	Quenched, drawn at 900 degrees.
2.5—3.5	80,000	68,000	20	52	Quenched, drawn at 1200 degrees.
2.5—3.5	71,000	50,000	22	64	Quenched, drawn at 1500 degrees.
4.5—6	121,000	107,000	12	50	Quenched from 1650 degrees F.
4.5—6	102,000	74,000	15	28	Quenched, drawn at 600 degrees.
4.5—6	88,000	63,000	20	51	Annealed at 1650 degrees F.
16—18	199,000	114,000	6	22	Annealed at 1650 degrees F.
22—26	114,000	50,000	35	73	Annealed at 1650 degrees F.
30	80,000	28,000	44	78	Annealed at 1650 degrees F.

TABLE 9. STRENGTH OF STEEL AS EFFECTED BY DIFFERENT AMOUNTS OF NICKEL.

section to slip over another with the load applied at some distance.

The shearing test is useful in determining the strain that bolts and rivets will stand and should be applied as its name implies, by having two jaws come

Alloying Materials Used.	Tensile Strength in pounds per square inch.	Elastic Limit in pounds per square inch.	Reduction of Area, per cent.	Elongation in Two Inches, per cent.
Carbon-manganese steel (plain)	56,000	34,000	60	35
The same plus 2.5 per cent. nickel	71,000	50,000	64	28
The same plus 3.5 per cent. nickel	80,000	68,000	61	20
The same plus 5.0 per cent. nickel	121,000	107,000	44	12
The same plus 0.5 per cent. chromium	72,000	46,000	61	33
The same plus 1.0 per cent. chromium	80,000	52,000	57	30
The same plus 0.10 per cent. vanadium	72,000	60,000	60	31
The same plus 0.15 per cent. vanadium	76,000	64,000	59	26
The same plus 0.25 per cent. vanadium	82,000	72,000	59	24
The same plus 1.5 per cent. nickel and 0.80 chromium	90,000	65,000	35	18
The same plus 2.5 per cent. nickel and 1.00 chromium	120,000	95,000	65	15
The same plus 3.5 per cent. nickel and 1.00 chromium	126,000	115,000	64	28
The same plus 1.0 per cent. chromium and 0.15 vanadium	102,000	76,000	57	24
The same plus 1.0 per cent. chromium and 0.25 vanadium	128,000	104,000	46	19
The same plus 1.0 per cent. chromium and 0.15 vanadium, hardened	178,000	148,000	48	16
The same plus 1.0 per cent. chromium and 0.25 vanadium, hardened	202,000	188,000	45	12

TABLE 10. EFFECT OF ALLOYING MATERIALS ON STRENGTH OF STEEL.

together over a piece of metal so they will just pass each other, and noting the number of pounds required to cut the metal in two pieces.

Transverse Strength and Impact

A bar supported at its two ends and struck in the center by a falling weight gives the resistance of the metal to shock or under impact. If the force is applied gradually the transverse strength is given.

By having the supports 12 inches apart, a test bar 1 inch square, a hammer weighing 500 pounds, and the hight of the fall 3 feet, as shown in Fig. 31, comparative impact tests can be readily made. The number of blows the metal will stand before rupture occurs and the deflection in inches from each blow are readily obtained. The deflection would be obtained by placing a straight-edge on the bar and measuring from this to the center of the test bar after each blow.

This shock test is used a good deal by the Krupp Steel Works of Germany with good results.

Another method which is a good one for ascertaining the capacity of metal to withstand shocks and blows, or in other words impact, is to fracture a cubic inch of metal by a given weight falling a given distance, or by the number of foot-pounds. The National Physical Laboratory of England has had a machine designed to make such tests and record them automatically, as they consider it a good guide for the specifications of certain parts of machinery.

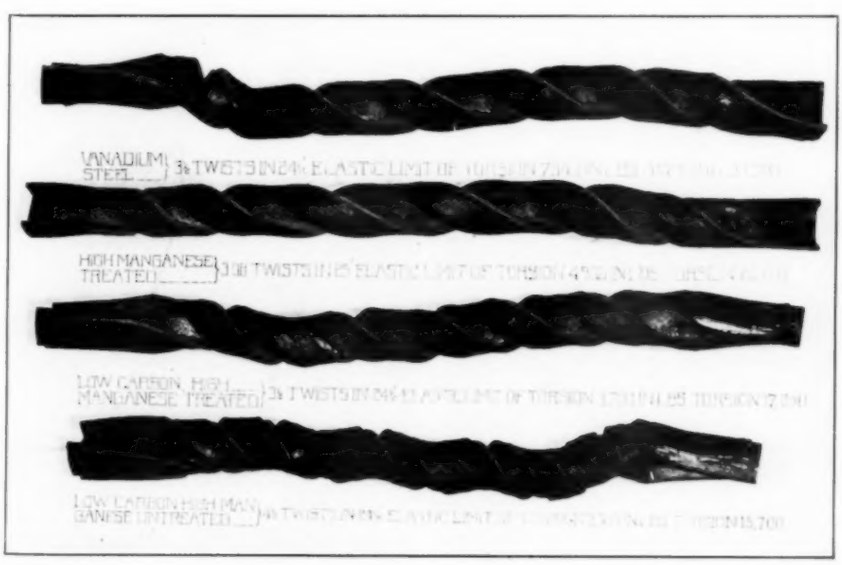


FIG. 30. RESULTS OF TORSION TESTS

The transverse strength can be obtained by connecting the gradually applied stress to a scales. The number of pounds that the test bar will stand before a permanent set takes place and before rupture occurs will then be easily obtained. From this can be figured the load that a given steel will carry between given centers. It is a very useful test for practical purposes.

Hardness

Hardness being a relative term it is hard to obtain a good definition for it and consequently many have been given. By hard steels are generally understood those that resist being scratched to the greatest degree or those in which the wear under friction is reduced to a minimum.

For measuring hardness many devices have been used with more or less dissatisfaction, owing to the difficulty of obtaining accurate results until the scleroscope was brought out last year.

The most commonly used devices were

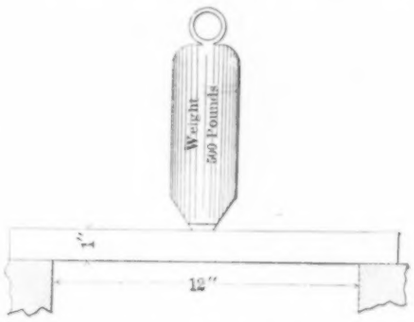


FIG. 31. IMPACT TEST

those of noting the relations between the number of revolutions and the depth of penetration of a drill which was run under a constant load and at a constant speed. This could not be made to work on the hard steels used for tools and therefore it was limited in its work. Another test was with the machine which gave in grams the result of a diamond scratch on a polished surface. A third is that of the indentation caused by a hardened ball of a given diameter being pressed into the metal under a given pressure and then measuring the depth of the indentation. The last two methods were very hard to apply owing to the fine measurements which were required and therefore were only used in the laboratory.

The scleroscope, as shown by Fig. 32, will test the hardest of steel or even glass as well as softer metals and the result is obtained at a glance, thus making it simple to use. In operating it a steel ball is dropped from a hight of 10 inches on an anvil block with a slightly rounded point. This will indent the test piece slightly and the ball will

rebound. The hight to which the ball rebounds will give the degree of hardness. The anvil block will sink into soft metals farther than into hard ones, hence the ball will rebound the farther the harder the metal.

Dynamics

Dynamics is the theory of forces in motion or the motions of a system of particles. Until very recently the dynamics of steel have not been thought of enough importance to submit the metal to tests of this character, but the rapid improvement which has been going on in machinery has produced problems which demand different qualities in steel from those found in the static tests. For instance, steels have been used in the moving parts of machinery which showed high qualities when submitted to static tests such as tensile strength, elastic limit, elongation and reduction of area, yet when used for a short time failed, these failures being claimed to be due to a crystallization of the metal to an extent that caused rupture.

Steels that will bear quite a load when steadily applied, or will bend under this load and will stretch considerably before breaking, do not always behave equally well when stresses of a different nature are applied. While the static strength and dynamic stresses seem to travel in parallel lines, this is not always the case and we see of late many failures due to the work which steel has to perform, which have been misnamed "mysterious failures."

These failures are usually due to the fact that the metal has been subjected to repeated applications of stresses which were far below the elastic limit yet caused progressive fracture by overcoming the molecular cohesion, and these in the end produced a fracture of the part in use. In this case there was no appreciable elongation and reduction of area and yet fracture occurred.

All steels will break or deteriorate in time, as everything has its life and death, but by making steels of higher dynamic properties it will prolong their inherent forces in motion and hence prolong its life.

Thus, as the static strengths are a good thing, these should not be reduced but the dynamic properties should be increased. We should not try to increase the static strengths to such an extent that the dynamic properties are neglected, if we are to get the best results out of steel, especially that used for the moving parts of machinery.

Alternating and Rotary Stresses

Alternating stresses are one of the most important of the dynamics of steel, as nearly all metals used in machinery construction are submitted to these more or less, owing to the vibrations which the metals are subjected to. These may take two forms, one being that of placing the metal first under tension and then under compression, and the other is that of applying the stress, then ceasing it and applying it again. The intervals between these applications should be short, so that the metal will not have time to rest between them. Another method of applying this stress is to bend a test bar in one direction and then bend it in the opposite direction in rapid succession.

A simple machine for doing this is shown in Figs. 33, 34 and 35, one of which shows the bar bent in, the second one showing it bent out, and the third shows the machine in operation.

This form of test will show the motions that a system of particles, such as steel is composed of, will stand before the cohesive force which holds these particles together ceases to act and the metal is ruptured. In other words, this shows that the metal's life has departed and death has occurred.

Rotary vibrational tests differ slightly from these, although they are very similar. These consist in twisting the metal until one end is distorted from its normal position and then twisted back in the opposite direction the same distance as shown in Fig. 36. These twists are usually made one-quarter of an inch from the normal so comparisons can be easily made.

One series of tests was conducted with this rotary vibrational test in which an ordinary carbon steel stood 20,000 twists, while a high-grade alloy steel stood 250,000 twists before rupture.

With this, as with the alternating bends, the greater distance the metal is bent from its normal position, the smaller will be the number of bends. The distance of the bend is therefore essential in making comparisons with other tests which have been made.

An extreme example of the submission of metals to these stresses is that of an

Kind of Steel.	Pendulum Impact, Foot-pounds.	Alternating Impact, Number of Stresses.	Falling Weight on Notched Bar, Number of Blows.	Rotary Vibrations, Number of Revolutions.	
				Stead	Southers.
Carbon axle stock.....	12.3	960	25	6,200	20,000
Nickel axle steel.....	14.0	800	35	10,000	
Vanadium axle stock.....	16.5	2700	69	67,500	100,000,000 not broken.

TABLE 11. TESTS OF DYNAMIC QUALITIES.

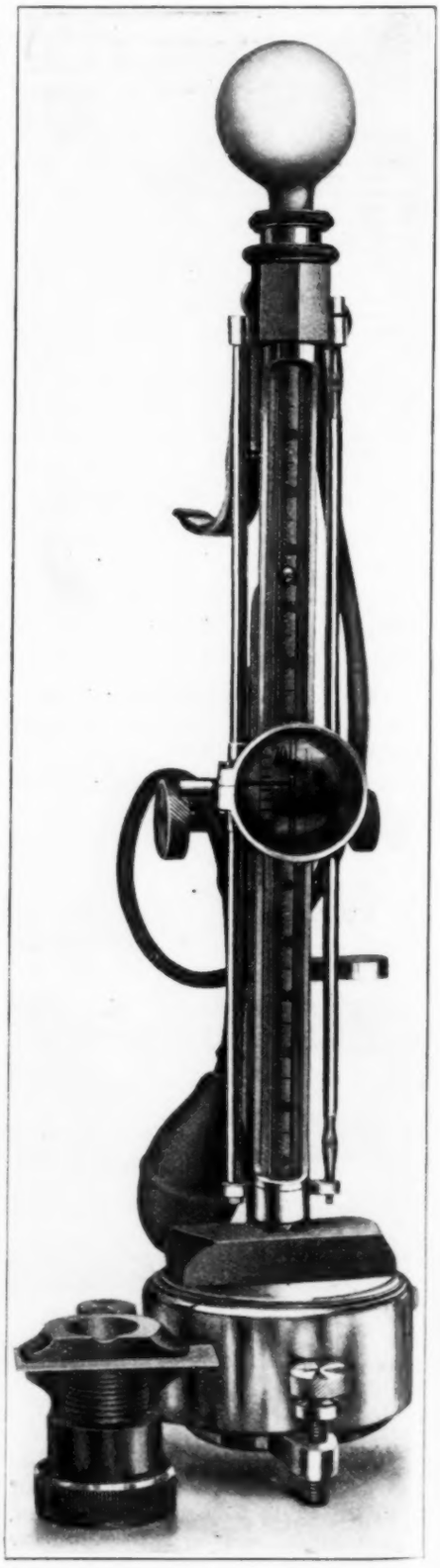


FIG. 32. THE SCLEROSCOPE

automobile in motion, as shown in Fig. 37.

Pendulum Impact

The pendulum impact tests are made by having a weight swing as a pendulum does and strike the test bar which is placed at the lowest point of its swing. The results can be obtained by measuring the number of foot-pounds which it takes to break the test bar with one blow, or the blow can be made lighter and the number of blows that are required to break it recorded.

A series of tests was carried on with a pendulum impact machine which showed a wide difference in steels of different compositions to resist disintegration, or in other words, the cohesive force was

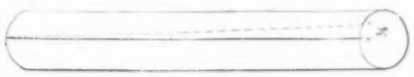


FIG. 36

much greater in some steels than in others. Care was used to see that all the test bars had nearly the same tensile strength.

The results of these tests are as follows: Carbon steel stood 11 foot-pounds, nickel steel 14 foot-pounds, and vanadium steel, 17 foot-pounds.

The shock was made less violent and repeated until the test bar broke. This showed 25 blows for the carbon steel, 35 for the nickel steel and 69 for the vanadium steel.

The impact was made much lighter and repeated at a very fast rate. This took 300 blows to rupture the carbon steel, 290 to rupture the nickel steel, and 540 blows to rupture the vanadium steel.

The conditions were next made very much less severe and the carbon steel stood 900 blows, the nickel steel 800 blows and the vanadium steel 2700 blows.

The conditions were again made much less severe, a permanent flexion being scarcely produced, but the alternations of stress were increased to 1200 per minute. This resulted in the carbon steel standing 6000 blows before it ruptured, the nickel steel 10,000 blows and the vanadium steel 67,000 blows.

Some other of the high-grade alloyed steels may show as good results as these, but as the figures are not at hand they cannot be offered in comparison.

Conclusion

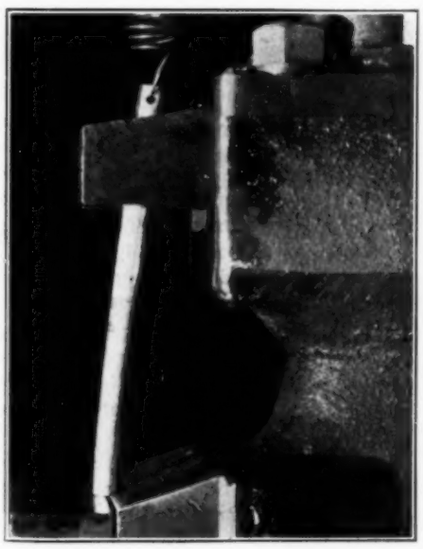
Table 11 shows some other dynamic tests which were made on different steels.

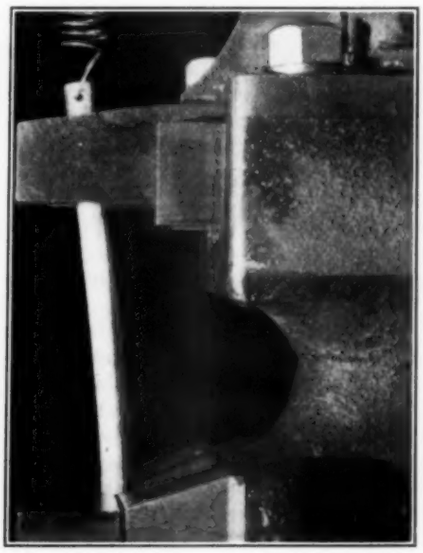
Steel castings have also been looked after in regard to their dynamics and locomotive side frames have been made which raised the alternating vibrations from 4700, as in the ordinary cast steel, to 14,900 in a special alloyed steel.

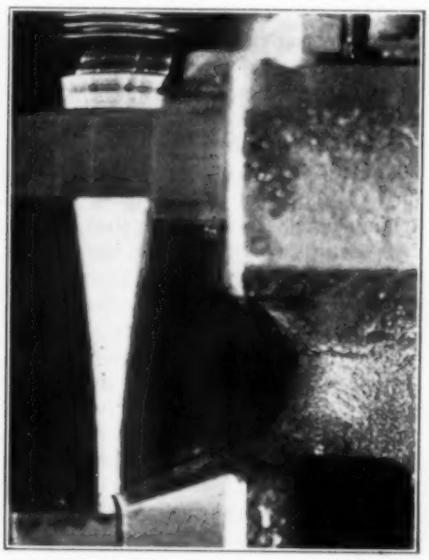
The results of these tests should show the necessity of increasing the dynamic qualities of steel so that its life may be prolonged and the accidents caused from steels of high strengths lessened, as these many times lead to the loss of life.

FIG. 37. VIBRATIONS OF AN AUTOMOBILE IN MOTION

Many of the railroad accidents of the past few years have been thoroughly investigated and found to have been caused by the steel in rails, tires, etc., suddenly breaking, due to their dynamic properties not having been what they should.







FIGS. 33, 34 AND 35. ALTERNATING VIBRATIONAL MACHINE. TEST BAR AT OUTER AND INNER POSITIONS AND IN MOTION

Working and Forming Steel into Shape

Methods Used in Rolling, Forging, Welding, Casting and Machining and Effects on the Strength and Grain of the Metal

Rolling

Crystal Formation

Steel which has cooled slowly from the liquid state, as is the case with that which has been cast into ingots from the converter, furnace or crucible, forms into crystals which do not show the same structure throughout. The outer shell of the ingot will have a different structure from the rest of the mass due to its cooling quickly and therefore it is under strains until the center of the ingot has cooled. The top of the ingot also has an area of abnormal crystallization which is due to segregation. There is, however, the same general crystalline character in the largest part of the ingot.

In passing the steel between rolls, to reduce it to the sizes and shapes wanted in the finished machine, this crystalline grain is broken up and a new grain which is much finer takes its place if the temperature of the metal during rolling has been kept slightly above its highest point of transformation, as at or just above this point a new grain structure is born which makes the metal more homogeneous.

This formation of grain continues after the steel leaves the rolls until it has cooled below its lowest point of transformation at which point it sets, and no more change will take place until the metal is heated to the critical point again.

In rolling steel it is frequently heated to from 2000 degrees Fahrenheit to 2400 degrees, and it would seem that this would seriously damage it. This would be so if it were not for the fact that the mechanical pressure exerted upon the metal by the rolls breaks down the large crystals formed by this high temperature and reduces them to a small size. The final size of the crystals is, therefore, dependent upon the temperature of the steel at the finish of the rolling process. Finished steel has a finer grain structure if the last rolling operation receives the metal at a temperature which is falling from 1650 degrees F. to 1400 degrees, which are the highest and lowest points of transformation, than if it is finished at 2000 degrees F. or any temperature above the highest point of transformation. On the other hand, if the rolling be continued after the temperature of the steel has fallen below the lowest point of transformation, strains are set up which make the piece unfit for use until it has been thoroughly annealed.

Rules for Rolling

Four rules might be established in rolling steels which will affect the final size of the grain so as to make it what it should be and these are: First, the rolling operations should be continuous from the highest temperature employed down to the finishing temperatures as long waits, such as are generally made necessary when the metal is formed roughly to shape and size at a high heat, then allowed to cool and a little work done upon it at the lower temperature, are liable to cause a coarse grain that will not be made fine by the last rolling.

Second: There are better results obtained if the steel is passed several times through the rolls with a small reduction in the size of the metal each time, than if a large reduction is made with a very few passes.

Third: In rolling a large piece a great reduction can be made during the first pass through the rolls, and the amount of reduction gradually decreased with each passage through the rolls until the finishing roll gives it just the right amount of reduction conducive to the making of the grain as fine as the steel will assume.

Fourth: The steel should reach the finishing roll so that the temperature will be falling from 1650 degrees F. to 1400 degrees, while it is passing through the rolls. It should not be allowed to go below 1300 degrees until all the rolling operations have been finished.

High and Low Temperatures

Steel is so mobile at very high temperatures that it yields to distortion by the crystals sliding past one another, but as the temperature decreases the mobility of the mass becomes less, and less sliding is possible. The crystals then crush against each other and at the lower temperatures a crushing of the crystals only takes place.

To obtain the very best qualities in a 0.50-per cent. carbon steel that it is possible to produce the work of rolling should be completed just at the time when ferrite begins to separate from solid solution. Rolling the work below the temperature at which this occurs, which is while the metal is cooling from 1650 degrees F. to about 1300 degrees, greatly increases the brittleness of the metal, while rolling the steel at a higher temperature lowers the strength, owing to the coarser grain which is given the metal. For steels of all other carbon contents it is logical to assume that the same rules hold good but it is possible, although not probable, that further investigations may change them.

Steels are rolled in a large variety of standard shapes such as round, square, oblong, hexagon, octagon, tubes, L, T, U, I shapes, etc., and can be obtained in nearly any special shape desired providing enough is wanted to pay for the making of rolls.

Casting

Apparatus for Melting

Casting steel consists of pouring the metal in a fluid state into molds which give it the desired shape. These shapes can be given most any kind of an intricate form owing to the shape being given the mold by a pattern and cores.

Many different methods are used for melting the steel and some of these are the same in principle as those used for converting the blast-furnace metal into steel.

The cupola has been used to a large extent but does not give good results, as the metal is much altered in remelting by the alterations in temperature and the exposure of the metal. The change in the metal is made by the absorption of the carbon and changes in the silicon and manganese.

Pig iron and steel are melted together in the cupola but this is not a normal product. It might be called a hybrid metal which is useful for special purposes, but fundamentally different from any kind of steel. It is a little better than cast iron and is a very cheap mixture comparatively.

The open-hearth furnace is used a great deal for melting steel, for steel castings, and might be considered the cheapest method of turning legitimate steel into castings. Scrap steel and iron are used in this furnace, but they are melted under an oxidizing flame and the metalloids are almost entirely eliminated, thus giving a definite starting point from which a known and regular metal can be made by the addition of recarburizers. In this country the acid open-hearth furnace is nearly always used, but in Germany many basic open-hearth furnaces are used.

The bessemer converter with its variation called the Tropenas process is used by many for making steel castings, and this if properly run gives good results in the castings. In the bessemer converter the blast is blown in at the bot-

tom, while in the Tropenas process the air is blown at a low pressure upon the surface of the molten metal. Some four to seven inches above this set of tuyeres is another set, which supplies air to burn the carbonic oxide, the upper set not being operated until the blowing is well under way. Some have adopted side blowing in this style of converter. It creates a greater amount of heat owing to the more perfect oxidation of carbon and to a burning of a proportion of iron.

The crucible process has been used to some extent for small castings, and to cast some of the special alloyed steels. Its condition of "dead-melt" gives a more quiet metal, generates less gas when the metal comes in contact with cold surfaces and the castings are more liable to be free from blow holes.

This method produces the best steel castings but it is the most expensive way of making them.

Risers, Gates, Etc.

In making steel castings about 40 per cent. of the melt is used to supply risers, sprues, gates, etc., and there is consequently a loss in remelting these.

The risers which are sometimes called sink-heads run from the top of the mold to the casting and are put on all thick sections of the casting to feed the metal to it while it is cooling and shrinking. These must be kept from solidifying until after the casting has become solid by continually stirring with an iron rod.

The sprue is the name given the opening into which the metal is poured and this runs from a pocket in the top of the mold to another pocket, which is usually located near the bottom of the casting. From this lower pocket to the opening in the mold which is to form the casting, are cut other openings so the metal will be able to flow in. These openings are called gates. This arrangement is made necessary to prevent the liquid metal from tearing up the mold, as it would do if poured directly into the opening that forms the casting. The metal left in these when the casting is poured has to be broken away from and chipped and sawed off of the casting. They are then remelted to make other castings.

Composition of Steel Castings

Steels with various alloying materials and of numerous different compositions are being used for castings today. The carbon content of these varies with the use to which the casting is to be put. Over 0.70 per cent. carbon is seldom used in castings owing to its making the steel too hard to machine, and in complicated shapes the shrinkage cracks are liable to become dangerous.

In the ordinary steel castings manganese should not exceed 0.70 per cent. for soft castings and 0.80 per cent. for hard ones, as more than this is liable to make the metal crack when shocks are applied to it. Silicon may have a percentage of 0.10 in the soft castings and 0.35 per cent. in hard ones without diminishing the toughness. Aluminum is used by many in making castings, as it has a great affinity for oxygen and will remove the last trace of this from the iron. It also aids in dissolving or occluding the gases. It has a tendency to make the metal sluggish but this will enable it the better to run through small passages as without it the metal foams and froths when it comes in contact with cold surfaces, thus impeding the flow and chilling the advance guard of the stream. Aluminum should oxidize out of the steel and not show over 0.20 per cent. when the steel is analyzed but it is better if only traces are left, as it decreases the ductility.

Sometimes the phosphorus is allowed to be as high as 0.08 per cent. but when the castings are to be submitted to physical test the phosphorus and sulphur should be kept below 0.05 per cent.

The physical properties of ordinary steel castings should be above the figures in the following table:

	Hard Castings.	Medium Castings.	Soft Castings
Tensile strength in lb. per square inch	85,000	70,000	60,000
Elastic limit in lb. per square inch	38,500	31,500	27,000
Elongation percentage in 2 inches	15	18	22
Reduction of area per cent.	20	25	30

A chemical composition which has given good results for locomotive side frames analyzed as follows:

Carbon	0.27	per cent.
Manganese	0.57	" "
Silicon	0.26	" "
Phosphorus	0.048	" "
Sulphur	0.033	" "

Test bars from this showed a tensile strength of 68,870 pounds per square inch, an elastic limit of 36,450 pounds per square inch, an elongation of 20 per cent. and alternating vibrations of 4707.

Vanadium-steel Castings

Vanadium has given such good results in rolled steels that it has been taken up by some of the steel foundries. In one case the usual mixture gave a steel showing a tensile strength of 68,580 per square inch, an elastic limit of 36,290 pounds, an elongation of 20 per cent. and resistance to alternating vibrations of 4706. To the above mixture was added 0.22 per cent. of vanadium. With this product added the following strengths were obtained: tensile strength, 77,160 pounds per square inch, elastic limit 46,450 pounds per square inch, elongation in 2 inches 20 per cent. and resistance to alternating vibrations, 14,971. It also increased the breaking strength to more than double and in some cases treble that of the ordinary steel.

It is in the vibrational stresses that vanadium shows its great superiority, and these tests were made on an alternating bending machine by gripping the test bar rigidly at one end and bending the free end upward and downward ⅛ inch from its axis. It gave a total length of stroke of ¼ inch, and this at the rate of about 30 strokes per minute.

Before adding the vanadium in the furnace it is necessary to have the oxides all removed from the metal, as the vanadium has a great affinity for oxygen. If any of the oxides remain in the metal, the vanadium will scavenge them out and go off in the slag, owing to its great elusiveness; but as vanadium is too expensive to use as a scavenger, the oxides should be removed before it is added to the steel.

Many failures in the use of vanadium in the past have been due to this elusiveness or its affinity for oxygen, as many thought that if they put the vanadium in the steel, it must be there after pouring. As a matter of fact, it might have completely oxidized out of the metal and not given it any of the desirable properties it is capable of.

With the oxides removed and other necessary precautions taken, the vanadium can be added with an assurance that it will be in the metal when analyzed; or more correctly speaking, that 90 per cent. of it will show on analysis, as a loss of more than 10 per cent. in the melting is uncalled for.

In using the acid open-hearth furnace for melting steel, the vanadium is added to the mixture just before tapping. The slag is raked from the top of the molten metal, the ferro-vanadium thrown in and the whole allowed to stand a few minutes, so that the vanadium will thoroughly mix with the metal.

As about 40 per cent. of the steel melted for castings goes back to the furnace, in the shape of risers, gates and sprues, to be remelted, the vanadium is lost in these owing to its oxidizing out during the melting process.

Nickel-steel Castings

Nickel added to steel in percentages of from 1.50 to 3.50 combines a high tensile strength and hardness, and a very high elastic limit with great ductility, therefore it is being used for steel castings with good results.

For some time it has been cast in large castings, such as rolling-mill gears and pinions and it is now being cast by a few foundries in small castings such as are used for automobile parts. It is difficult to cast in castings which have a thinner section in any of their webs, ribs, etc., than ¼ of an inch.

The ductility which lessens the tendency to break when overstrained or distorted combined with the very high elas-

tic limit, makes it valuable for such parts as crank-shafts on internal-combustion engines and these have been cast of nickel steel and given satisfaction in use, although forgings are much better for this purpose. Front axles, of I-beam section, have also been used successfully on automobiles.

Nickel-steel castings show a tensile strength of from 78,000 to 88,000 pounds per square inch, an elastic limit of from 50,000 to 58,000 pounds per square inch, an elongation in 2 inches of from 25 to 30 per cent. and a reduction in area of 40 to 48 per cent. This brings the elastic limit up nearer to the tensile strength than in the ordinary steel castings as well as increasing this and the elongation and reduction of area. This would indicate a greater resistance to shock and compression and the rendering of castings that are more ductile and tough than those made of the ordinary steel.

Direct-steel Castings

In this process the metal is taken direct from the furnace to a heated mixer where the proper materials are added to make the required quality of steel. The metal can be kept liquid as long as desired in the mixer and its chemical properties adjusted by the addition of different materials. The mixer is kept full by transferring metal from the furnace. When the metal is wanted for casting the mixer is tapped and the metal run into ladles from which it is poured into the molds as in other castings.

This process does away with the remelting of the metal in a cupola, converter, open-hearth furnace or crucible and its consequent losses from shrinkage. It produces a better and finer-grained metal by the mixer reducing the gases which come in contact with the metal in the cupola or furnace.

Castings of direct steel can be obtained with guaranteed physical properties as follows: tensile strength, 70,000 pounds per square inch, elastic limit, 35,000 pounds per square inch, elongation in 2 inches, 25 per cent. and reduction of area, 40 per cent.

These castings can be forged, welded and case-hardened and will machine as easily as machinery steel. They can also be bent freely when cold before breaking.

Manganese-steel Castings

Manganese steel with the manganese ranging from 12 to 15 per cent. and the carbon contents high, is being successfully cast and used for such parts as have to resist wear from gritty substances such as are encountered in rock crushers or in machinery used around concentrators.

Manganese steel has the peculiar properties of being so hard that it cannot be machined in combination with a malleability which enables it to be headed cold when made into rivets, and a toughness which gives it remarkable ability to resist wear and shock stresses as well as cold bending.

When they leave the mold manganese-steel castings are much more brittle than cast iron, but by heating them to about 1650 degrees F. and quenching in water, they are given their properties of great toughness and ductility.

Owing to their being too hard to machine all finishing must be done by grinding, but where it is desired to make a fit by machining, such as boring out a hub, a piece of metal that can be machined is placed in the mold and the manganese steel poured around it. By making this piece with numerous fins the manganese steel will shrink around it so that it will be nearly as firm as a solid casting.

The gases generated in pouring the metal are so low that the molds can be rammed very hard and with a fine sand. In this way surfaces are obtained that are nearly as smooth as finished castings and but little grinding is required when a finished surface is desired.

Its shrinkage is about double that of ordinary steel when cast and it cannot be cast in any very intricate shapes, nor can it be cast in any section which is thinner than ¼ of an inch.

When properly heat-treated manganese steel castings will show a tensile strength of 140,000 pounds per square inch, an elastic limit of 55,000 pounds per square inch and an elongation in 2 inches of 45 per cent.

Chrome-steel Castings

Where a great hardness is desired such as that required in the manufacture of projectiles, chromium is added to steel that is to be cast. This gives the metal a mineral hardness that cannot be obtained with any other alloying material and also refines the grain.

The uses to which these castings can be put is limited, however, owing to the difficulty of machining. The castings cannot be made in any intricate shapes or thin sections owing to the difficulty of making the metal flow easily, but for such things as projectiles no better steel has been found for casting and its usefulness is increasing.

Forging

For those parts which cannot be produced from the rolling-mill shapes, or made in castings, forging is resorted to and there are several different ways of turning out these forgings: by hand, under a steam hammer, in a hydraulic press, or in a drop-forging press. The cost of these different methods of production depends largely on the number of pieces required of the same shape, but the size of the piece to be forged as well as the components of the steel have an influence on which is the best as well as the cheapest method to use.

Hand Forging

When small pieces and but few of a kind are wanted, the hand forging is undoubtedly the cheapest; but for large pieces, or where a large quantity is wanted, hand forging is the most expensive way of producing them and the strength is not apt to be as great as by any of the other methods. With a blacksmith shop properly equipped, a skilled smith can make forgings that are stronger than a rolled bar from the same ingot. To do this the piece must be hammered between the proper temperatures, which varies with the different grades of steel.

A nickel-chrome steel must be kept at 2200 degrees F., which is a bright yellow color, all through the forging operations, while some of the carbon steels, particularly those that are high in carbon, cannot be heated to a temperature over 1800 degrees F., without burning the metal, and when once burned it cannot be returned to its former state without remelting. A vanadium-chrome steel will give as great strength as a nickel-chrome and can be forged as easily as a 0.40-per cent. carbon steel.

Effect of Carbon

The higher the carbon content the more danger there is of burning and a steel with 1 per cent. of carbon is very difficult to forge at all owing to the extremely low temperature at which it must be worked. The smith must also regulate the weight and effect of the blows so that it will be finished just as it reaches a blue heat. This will prevent the formation of large crystals, give the piece a dense, homogeneous grain with the atoms holding together by a high cohesive force and result in the steel having an increased strength.

The steel which is the best adapted for forging under the hammer has about the following composition: Carbon, 0.15 per cent.; silicon, 0.20 per cent.; manganese, 0.52 per cent.; phosphorus, 0.06 per cent.; sulphur, 0.04 per cent.

This steel in the annealed state will show the following physical characteristics: Tensile strength, 55,000 pounds per square inch; elastic limit, 30,000 pounds per square inch; elongation in 8 inches, 29 per cent.; reduction of area, 60 per cent.

When fractured it will show a silky fiber.

Using Higher-grade Steel

But for many purposes a steel of much greater strength than this must be hand-forged and then it becomes necessary for the smith to understand the nature of its component parts so he can forge it successfully, as many of the high-grade alloy steels can be rendered no better or stronger than the ordinary

carbon steels by over or under heating and poor workmanship.

In many cases welds are absolutely necessary to produce the required shapes and a steel of the following composition is the best suitable for welding: Carbon, 0.080 per cent.; silicon, 0.035 per cent.; manganese, 0.110 per cent.; phosphorus, 0.012 per cent.; sulphur, 0.007 per cent.

In the annealed state it should show the following physical characteristics: Tensile strength, 48,000 pounds per square inch; elastic limit, 25,000 pounds per square inch; elongation in 2 inches, 27 per cent.; reduction of area, 69 per cent.

Forging Under Steam Hammer

For pieces of considerable size and bulk the steam hammer is substituted for the hand-forging process. In this method of forging, the hammer should be of a size to suit the size of the work. The hammer-man must exercise a good deal of skill and judgment as to the power and speed of the blows delivered to the piece, as a too powerful blow will crush it and in the case of a high percentage of nickel, fissures and cracks are liable to develop which it will be difficult to get out, and which may show in the finished product.

This is especially true if the piece is allowed to fall below the forging temperature, or if the blows are not distributed evenly. If the blows are from a light triphammer, delivered at high speed, only the surface of the metal will be bruised and the core not affected, thus causing the core to be coarse-grained without the proper cohesion to insure the necessary strength.

A heavy hammer descending on work which is held at the proper temperature, at a slow speed, will penetrate the mass to the center and allow the particles of metal to flow to their proper position and insure a fine grain of even texture and be uniform throughout its entire size.

Forging Large Pieces

The keeping of the heat to a good forging temperature is more difficult than in the hand forgings owing chiefly to the difference in the size of the piece forged, as the hand-forged piece is usually small enough for the smith to put in the fire and reheat it the minute the temperature falls below the best forging heat. But the hammer-forged piece is many times large enough to be handled with a crane, and is therefore liable to be kept under the hammer as long as a blow will have any effect on it.

This results in a very uneven structure as when the metal is hot the blows will penetrate to the center, and as it cools they have less and less penetration until only the skin is affected, and the annealing, which is resorted to afterward, cannot bring it back to the proper homogeneity, as some parts will have a denser grain than others and therefore be stronger.

Drop-hammer Forging

When enough pieces, of one shape, are wanted to wear out a set of dies, the cheapest and best way of producing these in the high-grade alloy steels, is by the drop-forging process. They can then be made in one piece without welds, except in pieces which are many times longer than a section through them and these are so difficult to keep at the proper temperature that they are usually forged in two or more pieces and then electrically welded together. The oxygen-acetylene blowpipe has been brought into use for welds of this character, as well as all other forms of welding, and as good results are being obtained with this as with the electric welding.

A good illustration of this is the front axle of an automobile, which is usually forged in I-beam section, 4 inches from the top to the bottom of the I, 2½ inches across the flange, with the web ¼ of an inch thick, and a length of from 48 to 54 inches. These are generally forged in two halves and electrically welded in the center, but a few of them are forged in one piece, although the first cost of the dies and the liability of their breaking, owing to the axle cooling before the forging operation is completed, has made this method very expensive.

Drop Forging or Squeezing

In the drop-forging process two methods are employed, one being the ordinary drop-forging process, which hammers the metal into shape, and the other is the hydraulic press, which squeezes it into shape. With both of these methods dies are necessary, and these are usually made of a 60-point carbon steel and in two halves, an upper and a lower one, they being generally parted on the center line; but the shape of the piece controls the location of the parting line.

The dies are always given from 5 to 7 degrees draft, so the forging will fall out easily, and they are left open on the parting line from 1/16 to ¼ of an inch, according to the amount of metal in the forging. The amount of stock is always greater than in the finished forging, so it will completely fill the die, and the surplus is squeezed out at the opening on the parting line. This fin is afterward trimmed off.

Setting the Dies

One of the first and most important points in die forging is the setting of the dies, as the upper half, which is fastened to the ram, and the lower half, which is fastened to the anvil block, must come exactly in line to produce a perfect forging.

The lower half of the die should have a current of air blowing in it that is strong enough to remove all of the scale which works off the piece being forged. The air blast should be directed so it will not cool the hot metal being forged. Steel-wire brushes can be used for this purpose, but the air is quicker, and if well adjusted is more positive. The upper half of the die should be kept well oiled so the scale will not stick to that. This can be done by rubbing a swab, well soaked in oil, through the die every time it is raised off the work.

Accurate Forging

With the dies properly set and the press adjusted so the two dies will come together on the parting line, the work can be turned out to one thirty-second of an inch of the finished size, thus making much less machine work than by the hand-forging process, and when grinding is to be used in finishing, the work can be brought to within one one-hundredth of an inch.

After forging the pieces should be placed in a pickling bath, of a diluted solution of sulphuric acid, to dissolve the oxide or scale, after which they can be submitted to a sand blast, if a still better surface is desired.

The cost of drop forgings depends on the number needed and the number that can be turned out at one setting of the dies, as well as on the quality of the steel used.

Forging High-grade Steels

Thanks to the electric and autogeneous-welding process in combination with die-forging with either the drop hammer or the hydraulic press, all of the highest grades of alloyed steel can be turned into forgings successfully and their strengths and elongation retained, but this is almost impossible by the hand- or hammer-forging methods, especially if welds are made necessary by the shape of the piece. One of the alloy steels that is being manufactured into die forgings has the following chemical composition: Chromium, 1.50 per cent.; nickel, 3.50 per cent.; carbon, 0.25 per cent.; silicon, 0.25 per cent.; manganese, 0.40 per cent.; phosphorus, 0.025 per cent.; sulphur, 0.03 per cent.

In the annealed state this shows the following physical characteristics: Tensile strength, 120,000 pounds per square inch; elastic limit, 105,000 pounds per square inch; elongation in 2 inches, 20 per cent.; reduction of area, 58 per cent.

When properly heat-treated, that is, quenched in oil and drawn, these characteristics became: Tensile strength, 202,000 pounds per square inch; elastic limit, 180,000 pounds per square inch; elongation in 2 inches, 12 per cent.; reduction of area, 34 per cent.

Effect of Alloying Materials

Chromium produces a mineral hardness in steel and steels containing this alloy are difficult to forge, but if the temperature is kept above 2200 degrees Fahrenheit, or a bright yellow, and never allowed to fall below this it can be forged successfully.

This would require frequent reheating as the melting point is 2500 degrees Fahrenheit, and it cannot reach this temperature. With this steel it is best to make the dies with shorter steps between the different pairs than for the ordinary carbon steels.

Steels containing nickel are more easily forged, but these must be handled carefully owing to its tendency to produce fissures.

The vanadium steels are more easily forged than either of these, and if due care is taken to increase the heat gradually at first—that is, this steel should not be plunged into the heat all at once—no trouble will be experienced afterward.

Silicon in small percentages does not affect the forgeability of steel, but in large amount it gives steel a fibrous grain and is therefore used principally for springs. But in the last few years this steel has been forged into gear blanks to quite an extent. In this case the blanks should be made in the form of forged rolls, and not cut from bars, in order to avoid the fibrous structure.

The aluminum, tungsten, titanium, manganese and other alloyed steels are not used to any extent for forgings, as those before mentioned show superior qualities and some of the last named are much higher in price.

Hydraulic Press Gives Best Results

The inferior quality of many die forgings is undoubtedly due to the drop-hammer process, as this has a tendency to produce only a bruising effect owing to the top die descending at a high speed and delivering a light blow which has no penetration. The hydraulic press, on the other hand, produces forgings of a far superior quality because it slowly squeezes the metal into the shape of the die, thus allowing it more time to flow into place and assume its new shape and therefore making it more uniform in quality with a great deal lower degree of internal strains.

To remove the internal strains caused by working the metal all forgings, no matter how they are made, should be annealed before using, as the shocks to which the forging may be submitted will concentrate at the point where these internal strains are the strongest, causing it to break at that point. The results are very similar to the machinist notching a bar in order to break it.

Heating Too Suddenly

Many poor forgings are also turned out by raising the temperature of the metal too suddenly. Certain molecular changes take place in the heating of all steels, and of the alloy steels in particular which are liable to cause fissures in the core of the metal and these may not show in the finished product as they do not always break through the skin or outer shell of the forging. Thus by heating suddenly the outer shell becomes red before the core has had an opportunity to absorb any heat and the outer shell expands, causing great strains on the core of the piece.

In the case of a high percentage of nickel these fissures become more pronounced than with the other alloys.

At a temperature of about 600 degrees Fahrenheit or a bright blue, most steels lose their ductility and are not fitted to resist strains imposed upon them by the differential expansion of an unevenly heated metal. Therefore the rise in temperature from the normal to 600 degrees, should be a gradual one, but after this it may be brought up to the forging heat as quickly as is desired.

Welding

In many of the more intricate shapes that are hand forged, a resource is had to welding and if the average smith were told that he could not make a perfect weld he would feel greatly insulted. But from a large number of so called perfect welds that were examined very few showed a strength equal to 50 per cent. of the unwelded section. With the alloy steels it is difficult to get a weld that will even show that percentage as nickel, chromium, vanadium, tungsten, aluminum and some other alloys do not lend themselves to the welding process and it is difficult to make welds at all when these are ingredients of the steel to be welded by the hand methods in a blacksmith's forge. Some of these steels have been welded, but an efficiency of over 25 per cent. is seldom obtained.

Carbon, however, is the principal enemy of welds and with this as low as 0.15 per cent. it must be handled with great care at the welding heat, while with 0.20 per cent. of carbon the steel is very unreliable and with 0.50 per cent. of carbon the steel is liable to be burnt at a temperature well below the welding heat.

Thus to make hand forgings where welds are necessary the pieces must be from 2 to 3 times the size of that necessary for the required strength and with some of the alloyed steels even this will not suffice.

Principles Involved

Welding consists of heating two pieces to a high temperature, then dissolving off the iron oxide, which has formed on the surface, by the use of some flux, such as borax, and then firmly pressing the pieces together. Welding plates are sometimes put between the pieces to be welded in place of the borax. These are special preparations which are made for this purpose and are covered by patents.

The exact temperature to heat pieces to for welding is not known, but it is near the melting point as the steel must be in a soft, almost pasty, condition. The pieces are usually upset or enlarged at the ends, so that the section at the weld will be larger than the rest of the piece. In the ordinary weld they are hammered continuously until the metal has cooled to a dull red. This breaks up the coarse crystals which have been produced by the high temperature and by finishing at a low temperature, a small grain is secured.

This small grain is obtained, by proper welding, in the metal close to the weld, but there is always a place within a short distance of the weld which must have been heated to the high temperature, which means overheated, and has not received the mechanical treatment given at the weld by hammering it down to the proper finishing temperature. This will cause the metal to have a coarse grain at this point, which is usually from 4 to 8 inches from the weld, and the metal will break at this point when submitted to a strain much less than the original strength of the metal welded. Thus, while the average welder may say that if no break occurs at the weld it is as strong as the original piece, this is not true and welds are seldom made by hand methods that have more than 60 per cent. of the efficiency of the original piece. In a large number of tests which were made it was found that the cause of damage was the bad crystallization adjacent to the weld.

Restoring the Metal

All steels which have been welded would give better results if they were reheated to a little above 1650 degrees Fahrenheit, as this heating would restore to a large extent the grain size of all parts.

Steel is overheated when the first drops of melted metal begin to form in the interior of the mass. These segregate to the joints between the crystals and cause weakness. The second stage of this is when the molten drops segregate as far as the exterior and leave behind a cavity filled with gas. The third and last stage is reached when gas collects in the interior under sufficient pressure to form miniature volcanos and break through the skin. This projects liquid steel and produces the well-known scintillating effect of this temperature. Into the openings formed by these miniature explosions air enters and oxidizes the interior. Mechanical pres-

sure applied to the steel such as squeezing, hammering, etc., if carried on continuously until the metal has cooled to a dull red, will bring the steel back to its original condition and grain. By reheating to a little above 1650 degrees after the piece has been welded, will also aid in restoring it to its original condition.

Electric Welding

The hand method of welding being a slow, laborious process when large pieces were to be welded and the efficiency of the welds being low, it became necessary to abandon welding in many cases as a commercial possibility, or to invent some other means of performing the welding operation. This necessity brought into use the electrical welding process.

In this process the pieces to be welded are usually butted together and clamped so there will be a pressure against each other. Two electrodes are then placed on each side of the joint to be welded and the current of electricity passing through these also passes through the steel at the joint. This softens the metal by heating it nearly to the melting point and the pressure of one piece against the other squeezes them together until they are welded.

This process has many advantages over the hand method. The heating can be located and held in the immediate vicinity of the weld and the hand can be held on the metal but a very few inches back from the weld. This prevents the metal from crystallizing 6 or 8 inches back as in the forge-heated piece; the temperature of the surfaces to be welded is always under control which reduces the danger of overheating the steel to a minimum. The necessary pressure between the abutted pieces may be regulated to any pressure desired; very irregular shapes may be butted together and welded in a very accurate manner. The efficiency of the weld has been increased 50 per cent. and in some cases 100 per cent. over that of hand welding.

Alloyed steels that do not lend themselves readily to welding by hand can be successfully welded by the electrical process.

The density of the metal is much more uniform when welded by electricity than by the hand method, and the weld is made in a fraction of the time.

The amount of work required in finishing after electric welds is very small as it leaves it comparatively smooth; a slight ridge right at the weld being practically all the deformation there is in the metal.

This has aided greatly in the production of forgings as they can be made in two, three, or more pieces and afterward welded together. It has also been found in many cases to be a better method than brazing and in such cases is used in place of it.

Autogeneous Welding

All of the benefits derived by welding with electricity can be claimed for this method as it confines the heat closely to the welded surface and the heat is under perfect control.

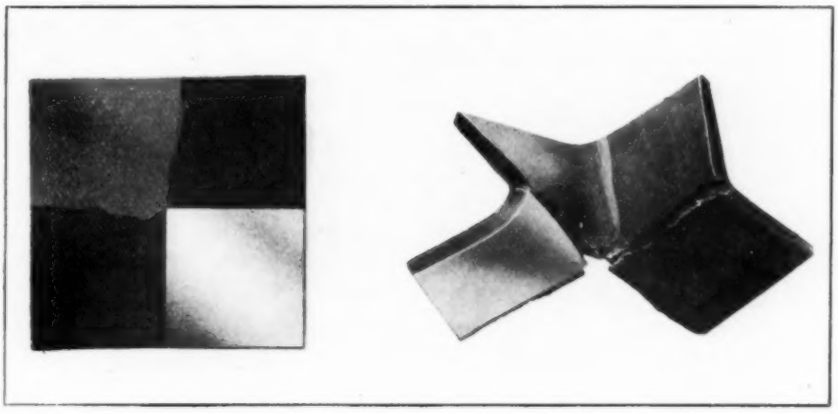


FIG. 38. STEEL, COPPER, BRASS AND BRONZE WELDED TOGETHER

This process consists of heating the metal by a blow pipe using oxygen and acetylene gas. With this the metal is heated to the melting point and a steel rod is passed along with the flame, steel melting off from the rod and flowing into the joint until it has been filled.

The flame is largely carbon monoxide but at the tip where the heating takes place it is converted into carbon dioxide. This gives a flame that will neither carbonize or oxidize the metal. In lighting the blow-pipe, the acetylene is first turned on full, then the oxygen is added until the flame has only a single cone whose apex has a temperature of 6300 degrees Fahrenheit. Too much acetylene produces two cones and a white color, while an excess of oxygen is shown by the flame assuming a violet tint. The best welding results are obtainable with 1.7 volumes of oxygen to one of acetylene.

The oxygen for the process is obtained by using a special generator which has two lead-lined chambers with a scrubber and settling chamber between them.

In one generator is put a chemical charge of calcium compound and copper sulphate and the generator filled with lukewarm water after which the solution is stirred.

In the second generator a solution of iron sulphate and water is poured. These two solutions produce a large quantity of oxygen which is passed through the scrubber into a receiving tank. The oxygen is drawn from this tank by an air compressor which compresses it to 147 pounds in a storage tank from which it is taken through copper pipes to the point required.

The acetylene gas is manufactured in the ordinary way from calcium carbide, and used at a pressure of 2 or 3 pounds.

Application

Through a system of piping, the flame is easily carried to the work which saves the labor of moving large pieces of work to a forge or hammer for welding. Pieces one inch thick have been successfully welded with this process, but its best application is in welding sheet metal as joints of great length can be easily welded. In fact its only limit is the length of the joint and the time needed and this latter can be carried out indefinitely.

Oxy-acetylene welding gives its best results in the welding of steel, but cast iron is being welded successfully as well as copper, brass and bronze. The different metals can also be welded together as is shown in Fig. 38 in which four plates were butted together and welded.

One plate was steel, as shown by the white square; another brass, as shown by the darker square in the diagonally opposite corner; and the two very dark squares were copper and bronze respectively. After welding these they were bent and broken at the joints to see if they were thoroughly welded and from the appearance of the fractures they would indicate a perfect weld. The steel welded to the copper and bronze as well as the brass did. Owing to the high heat of the flame, however, the lead and zinc in the brass and bronze melted out, leaving holes in the metal.

Welds of 90 per cent. efficiency can be made with careful workmanship and the cost in wages and gas for welding plates ⅛ of an inch thick is about 2 cents per foot.

A variation of this process has been made which cheapens the oxygen so that it can be made to cover a wider field of usefulness. This is the discovery of an oxygen powder which has been named "epurite." It is a substance containing oxygen in a latent state, and a form susceptible of easy liberation on contact with water. There is said to be no

danger of explosion in connection with this process as there is no large quantity of gas stored in tanks under high pressure.

Oxygen and hydrogen are also being used in the proportion of from 2 to 4 parts hydrogen to 1 of oxygen, and the hottest part of this flame is about ⅝ of an inch from the point of the burner.

Two parts hydrogen to one of oxygen will give a flame with a temperature of about 4350 degrees Fahrenheit, but if a flame is desired with a reducing action it is necessary to use 4 parts of hydrogen to 1 of oxygen and this will have a temperature of about 3450 degrees Fahrenheit. This flame will melt iron and cause it to weld even if the surfaces are not clean, as any rust present will be reduced.

This lower temperature of the flame is really better for sheets up to ⅛ of an inch thick, as the melting of the metal is less rapid and less explosive, giving a welded joint that is cleaner and with fewer scars and blisters.

Thermit Welding

The thermit process of welding is radically different from all the other processes and is useful for an entirely different class of work.

With this process, a sand mold is built around the pieces to be welded and the metal poured in this. The mold is made of sand and clay, which should be mixed thoroughly stiff and as dry as possible, as the less moisture there is in the mold the better will be the results obtained. For this reason the mold should be dried in a furnace or oven at a low temperature for from six to eight hours. To test the dryness of the mold, two or three wires can be rammed up in the thickest section of it and these pulled out after drying to see if any moisture remains.

With the mold completed the thermit is placed in a special receptacle which is located over the mold. The thermit consists of aluminum and oxide of iron. A little magnesium is placed in this and lighted with a match which immediately sets up a tremendous chemical action which produces a superheated liquid steel and superheated liquid slag which is aluminum oxide. When the mass is entirely molten it attains a temperature of 5400 degrees Fahrenheit. The bottom of the receptacle is then tapped and the liquid metal runs into the mold and into and around the joint to be welded. The high temperature of the liquid mass causes the ends of the pieces to be welded to become molten and pasty, and fuse with the thermit.

Welds were made with this process on a bar of rolled steel, 2 by 4½ inches which was broken and welded and then tested. The tests showed an efficiency of 97 per cent. in tensile strength and 88 per cent. in elastic limit.

The greatest usefulness of this method of welding is for the stern frames of steamships which have broken, locomotive side frames, driving wheels or connecting rods and other things of a similar nature, but the building of the mold makes it commercially prohibitive where autogeneous or electric welding can be used economically.

Machining

Different Methods Employed

In machining steel many different methods are used, such as turning, planing, milling, drilling, profiling, grinding, etc., and the one which is the best to use depends largely on the size and shape of the finished piece although the method of making the piece, such as rolling, casting, forging, etc, has a bearing on which method will give the best results, as for instance, castings whose surfaces are filled with hard gritty sand might be ground to better advantage than finished with cutting tools owing to the sand having a tendency to dull the tools. Then again the composition of the steel might have a bearing on the method to be employed, as for instance, chrome steels are very difficult to cut with machine tools while manganese-steel castings cannot be cut at all but must be ground.

Another method which might be classed with the machining of steel is the use of the autogeneous welding apparatus for cutting steel. It is especially applicable for cutting holes in steel pipe where it is necessary to fit a nozzle, and for this class of work it is much quicker and consequently cheaper to melt a narrow slot through the steel with a blowpipe than to cut it out by the old method of drilling and then cutting it with a cold chisel or hack saw.

Cutting Speed

The effect of the quality of the steel to be machined on the cutting speed is rather a difficult problem to set any hard and fast rules to, as it is affected by so many different things, notable among which are the materials entering into the composition of the metal, the temperatures at which it has been heat-treated, the density of the metal as affected by hammering or squeezing in forging and in pouring into castings or in rolling into shape and the composition and shape of the tool used to do the cutting.

In the ordinary grades of steel the carbon content can be used to judge the speed at which they should be machined, if the metal is thoroughly annealed and a known brand of steel used in the cutting tools. Practical experience in the shop will also enable one to set standards of cutting speeds for some of the special alloyed steels if the specifications under which these are purchased are of such a nature as to guarantee a uniformity in the pieces purchased at different times.

Table 12 gives the cutting speed and the pounds of turnings of a few grades of steel. These were cut with a high-speed steel and the depth of cut was 3/16 of an inch with a feed of 1/16 of an inch. While these figures are the results obtained under certain conditions they can only be used in a comparative way owing to other conditions, which many times may seem of a trival nature, altering them.

The physical properties of steel have also been taken as a guide to the cutting speed of steels and these form a fairly accurate guide for nearly all steels but there are exceptions to this, as for instance in the case of the alloying material vanadium, which increases the cutting speed of steels that have high physical properties.

The Steel Machined.	Cutting Speed in Feet, per Minute.	Pounds of Turnings per Hour.
0.10 per cent. carbon steel	100	295
0.20 per cent. carbon steel	75	222
0.30 per cent. carbon steel	63	176
0.40 per cent. carbon steel	51	150
3.50 per cent. nickel steel	55	163
0.25 per cent. carbon, 0.75 per cent. nickel and 0.80 per cent. chromium	50	148
0.25 per cent. carbon, 1.50 per cent. nickel and 0.80 per cent chromium	45.5	135
0.45 per cent. carbon, 1.50 per cent. nickel and 0.80 per cent. chromium	35	103

TABLE 12. COMPARATIVE CUTTING SPEED IN TURNING DIFFERENT GRADES OF STEEL.

The cutting speeds of steel as well as the grade of steel which is the best to use for cutting tools and the shape in which these tools should be ground has been very thoroughly covered by F. W. Taylor in his book entitled, "The Art of Cutting Metals." Mr. Taylor, in conjunction with Messrs. Barth and Gantt, has also invented a slide rule by which the speeds of steels of known properties should be cut to get the best practical results and effect the greatest saving.

All of these methods and rules, however, are in reality only comparative, and it is up to the man in charge of any given department where steels are machined to establish his own rates of cutting speeds from the practical experience of himself and those doing the work, but the rules laid down are a great aid in establishing the standards at which steels should be machined.

Echoes from the Oil Country—A Pump with some Peculiarities

By W. Osborne

It was eminently fitting that anyone having something new in the pump line should desire to come to the oil country with it for there pumps are used in abundance and of many kinds, from the deep well pump that will bring the oil up from a depth of several thousand feet, to the high-duty one that will send it through a pipe over the mountains. They can be found in all kinds, types and sizes, high duty and low duty, rotating, reciprocating, vertical and horizontal, direct acting, steam driven, air, gas or belt driven, simple and otherwise. They can be found working against pressures of from 2000 to the square inch down, and are used to move oil, water, tar, acid, gas and many combinations of them.

To a man with something new in the pump line it would seem to be a good place to put it to use, and that may explain how this new pump came to be attracted by the oil country. Judging from reports quite an influential portion of the oil country was attracted by this new pump or by the description which they received of it. It had many remarkable features, but the one that was most in evidence was that it had a remarkable way of delivering a very large amount of water with a very, very small amount of power used to run it.

Among the wonderful combinations used to produce these most wonderful results was found that "most wonderful of all power producers, the fly-wheel," and "the lever, which allows us to increase our power to any extent which we may desire," and besides all this by the genius of the designer "we produce an equilibrium whereby the fluid which had just been raised helps to raise that which follows."

Having such a genuinely wonderful pump a factory might have been started and the public kept away from any of the benefits except such as they would receive from buying and using the pumps; but as these pumps were bound to take the place, it time, of all others, it was believed to be better to allow the public to share in every way so as to reduce the suffering.

The most prominent men in the community were interested in the matter—lawyers, doctors, financiers, merchants and other business men. With more than even their accustomed stupidity the mechanics held back and tried to look wise. You can realize how hopeless it would be for them to try to undo, in the mind of a lawyer for instance, the logical deductions of the highly educated promoter.

After a man had been sent to see one of these pumps and the marvelous work it was doing the enthusiasm became very great. The papers devoted lots of space to the subject and the town was congratulated on the golden opportunity to still keep in the pump business. Finally a pump was brought and set up where it could be seen, and interested persons could pump with it and find for themselves how little power it really needed. Some of the machinists from the shops went and tried it and were convinced. Of course once in a while one of them tried to get smart and ask questions which were not in good form, as they seemed to hint that everything was not as rosy as it appeared, but a few pointed questions from the man in charge always showed that the enquirer had very little knowledge of the real essence of physics. The matter generally ended with the man who had started the trouble leaving with a very red face, and followed by the laughter of the gentlemen there assembled. The man in charge would then explain how ignorant of principles the people who have to do with shops really are and show how the work there is all entirely "mechanical," the real brains having been furnished by James Watt, and Howe, and Bessemer, and Thomas Edison.

Among the men who were interested in this pump proposition were some shrewd business men who had faith in the mechanics of the town and were not ready to believe them all ignoramuses. They knew that they would have to pay to get an opinion from a lawyer, or a prescription from a doctor, but they did not value the opinion of a mechanic highly enough to think it worth pay although many of them tried to get free opinions.

"What do you think of this new pump?" asked one man of his mechanical friend.

"I haven't seen it," replied the friend.

"By using a fly-wheel they get lots of power and it runs very easy. You can run it with just one finger." This man had tried it.

"How long will it be do you suppose, until the engine builders get onto that scheme. It will be great when a man can make all the difference in the power of his engines in the size and weight of the fly-wheels. It seems funny that nobody ever found it out before," said the mechanic.

"It might seem so at first but then I don't know as it is when you come to think of it. I was reading in a scientific paper the other day that if a piece of steel is heated so that it is just beginning to melt and then cooled in the air it will do several times as much work as you people ordinarily get out of it. With mechanics using steel since the world began, almost, one would think some one would have found that out before. Wouldn't you, now?"

An inquiry as to the kind of steel did not bring any information. Steel was steel to this man, and the mechanic felt that the lack of information was too great to be removed easily. He thought the pump a better subject. "You have been examining the pump. Let me hear some more about it."

"Well, they have several different varieties. In one, for instance, they have a short walking beam and while one end does the pumping the other end has a cylinder on it that is filled with the water, or whatever it is that the pump is pumping. This cylinder going up and down balances the work of the other end to a great extent."

"That is a point that I couldn't quite understand. It's like putting a rock on the other side of a horse to balance the bag of wheat."

"Come, come, now. You are making fun, but for all that, did you not tell me yourself that an oil-well power, that is to say mine up on the hill, would run easier if I put a dummy on the up-hill side and loaded it with a ton or so of stone?"

The mechanic had to confess that he had given such advice, and as he had not seen the pump he could not demonstrate that it did not make a gain by similar means.

Quite a number of machinists had been taken in to see the operation of these pumps and were very enthusiastic over what they saw. Some of them were trying to raise money to invest in the stock of the company that was about to be formed. Several of the men who were foremost in wanting to get the pump works in their home town and who were willing to put money into the proposition, felt that as it was likely to get to be a sort of general affair they would like to get the public indorsement of some man well known in the affairs of the place and who was connected with the manufacturing interests. They knew that good business propositions do not always turn out to be money makers, and that it is hard to explain things to the general public when they do not. One day they induced a friend of theirs, who was at the head of the largest works in the place, to go with them "Just to see the pump." This pump was being operated by a small electric motor. The current was obtained from the local commercial company.

This gentleman went and saw. He listened to what they had to tell him. He saw the stream of water that the pump was handling. He measured the hight of the lift. He took their statement for the quantity of water handled per minute. He saw the amount of current it took to run the motor. He had not intended to say anything, but a sarcastic remark from the man in charge changed his mind.

"Isn't there any chance of there being any mistake in your statement of the quantity of water handled, and of the power that it takes to do it?"

It was quickly demonstrated to him that there could be no mistake. He was free to measure for himself if he cared to do so.

"Oh, no. I am not particularly interested in the matter. I just happened to

notice that your electric motor is using about six times the amount in electrical horse-power that your pump is delivering in water, and thought that perhaps you had not given me the correct figures."

I have not had access to any figures showing what the performance of this wonderful pump would be without the help of the fly-wheel, the lever and the equilibrium but this section is not to be favored with a manufactory.

Quite a lot of valuable time might have been saved if one of these pumps had been delivered to one of the shops with orders to test it and report efficiencies, but one thing was demonstrated time and again, and that is that it is hard for an honest man who is well informed, practically, on machinery to convince educated men who are not informed on mechanical matters against the arguments of one who is both educated and well informed and who is using all of his powers to mislead.

This is not the only performance of the kind that has interested the inhabitants of the oil country, but it is one of the latest.

Business Items

Ridgway (Penn.) Dynamo and Engine Company has opened a district sales office at 907 Andrews building, Cincinnati; Geo. W. Enker, manager.

The Cincinnati Chuck Company is now established in its new plant on Spring Grove avenue, Cincinnati, Ohio. and is fully equipped to turn out a complete line of independent, combination, universal and geared scroll lathe chucks.

Trade Catalogs

Allis-Chalmers Company, Milwaukee, Wis. Bulletin No. 1513, illustrating and describing portable air compressors.

Western Electric Company, Hawthorne, Ill. Catalog of general supplies. Illustrated, 838 pages, 7½x10 inches, cloth.

The Brown Hoisting Machinery Company, Cleveland, Ohio. Catalog describing locomotive grab-bucket cranes. Illustrated, 40 pages, 6x9 inches.

General Electric Company, Schenectady, N. Y. Bulletin No. 4561, illustrating and describing Edison "Gem" high-efficiency incandescent units. 16 pages, 8x10½ inches.

George W. Jackson, Inc., Chicago, Ill. Catalog descriptive of interlocking steel sheeting for bridge foundations, piles and casings for building foundations, etc. Illustrated, 70 pages, 7x10 inches, paper.

Fort Wayne Electric Works, Fort Wayne, Ind. Bulletin No. 1104, describing multiphase belted alternators, form B. Illustrated, 8 pages, 8x10½ inches. Bulletin No. 1105, describing electric fan motors. Illustrated, 8 pages, 8x10½ inches.

The Breeze Carbureter Company, 276 Halsey street, Newark, N. J., Pamphlet entitled "Carbureters and Engine Troubles" which describes the principle and operation of the Breeze carbureter. Illustrated, 32 pages, 3½x6 inches, paper.

Manufacturers

The Wabash Company will erect a large roundhouse at Delray, Mich.

E. L. Fields Company, Bossier, La., will establish a woodenware factory.

The plant of the Bryant Machine Company, Seekonk, Mass., was destroyed by fire.

A large foundry building will be erected for the Standard Oil Company at Oil City.

The John Grossius Furnace Company, Cincinnati, Ohio, will erect $15,000 factory building.

The Rock Island System is said to be planning to establish large car shops at Hot Springs Junction, Ark.

Sneed & Jamison, Greenwood, Miss., will establish a plant for the manufacture of columns and pumps.

Tanners & Dyers Extract Company, Charleston, W. Va., will build a paper-pulp plant at a cost of $150,000.

The American Can Company of New York and elsewhere, it is reported, will build a $1,000,000 plant in Montreal, Canada.

The Taska & Meyer Ornamental Woodworking Company, a new concern, is building a plant at West Allis, Wis.

Plans have been completed for shop and foundry building for the American Brass Manufacturing Co., Cleveland, Ohio.

James B. Clow & Sons, of Chicago, Ill., will erect a plant at Coshocton, Ohio, for the manufacture of cast- and wrought-iron pipe.

The Leader Iron Works, Decatur, Ill., has increased its capital stock. Plans are being considered for the extension of the plant.

A. E. King, of Huntsville, Texas, contemplates establishing a plant in Beaumont for the manufacture of furniture and woodenware.

Hafer & Foust, implement dealers, Chambersburg, Pa., are erecting an addition which will be used as a blacksmith and woodwork shop.

The C. G. Garrigus Machine Company, Bristol, Conn., organized at $50,000, has acquired a site for a plant. Special machinery will be manufactured.

Fire destroyed the plant of the Fifield Machine Company, Lowell, Mass., causing a loss of $300,000. It is announced that the plant will be rebuilt.

The Youngstown (Ohio) Sheet and Tube Company has purchased the plant of the Morgan Spring Company at Struthers, Ohio, and will increase the output.

Plans have been completed for a new cannery building for the Montesano (Wash.) Fruit Growers' Association. This is to be equipped with the latest machinery.

The Nashville (Tenn.) Foundry Company has been incorporated and is now putting up a seven-story plant. J. W. Satterwhite, O. H. Looney, M. R. Wilhite and others, incorporators.

The Norfolk & Southern Railway Company is having plans prepared for railroad shops at Chocowinity, N. C., to cost about $300,000. T. W. Cothran, Raleigh, N. C., assistant engineer.

The Model Manufacturing Company, Paris, Texas, has been incorporated to manufacture sash, columns, brackets, etc. W. B. Ward, L. A. Albright, A. M. McCormick, incorporators.

The Gatling Lumber Company, Charlotte, N. C., has been incorporated with $25,000 capital to manufacture doors and blinds. E. P. Gatling, of Freeman, N. C., is one of the incorporators.

The Pierce Safety Appliance Company has been formed at Wheeling, W. Va., and will establish a plant at Moundsville. The company is capitalized at $500,000 and principal office is at No. 1321 Market street, Wheeling.

The Regan Foundry and Hollowware Company is erecting a plant in Bessemer, Ala., for the manufacture of stoves, castings and hollowware. W. W. Hollingsworth, president of the Bessemer State Bank is behind the company.

The Deadwood (S. Dak.) Business Club is organizing a company with $100,000 capital, for the purpose of rebuilding the foundry of the Black Hills Mfg. Co. which was destroyed by fire. J. C. O'Donnell, owner of the old foundry, is interested in the company and will manage the plant.

Want Advertisements

Rate 25 cents a line for each insertion. About six words make a line. No advertisements abbreviated. Copy should be sent to reach us not later than Friday for ensuing week's issue. Answers addressed to our care will be forwarded. Applicants may specify names to which their replies are not to be forwarded, but replies will not be returned. If not forwarded, they will be destroyed without notice. No information given by us regarding any advertiser using box number. Original letters of recommendation or other papers of value should not be inclosed to unknown correspondents. Only bona fide advertisements inserted under this heading. No advertising accepted from any agency, association or individual charging a fee for "registration," or a commission on wages of successful applicants for situations.

Miscellaneous Wants

Caliper list free. E. G. Smith Co., Columbia, Pa.

If you use small gears in large quantities, write Berry and Parker, Erie, Pa.

Wanted—American Machinist, No. 45, Volume 30. Canadian Locomotive Co., Kingston, Ont.

We buy or pay royalty for good patented machine or tool. Box 282, AMERICAN MACHINIST.

Hand power bending tools, labor-saving, money-making. Estep & Dolan, Sandwich, Ill.

Light, fine machinery to order; models and electrical work specialty. E. O. Chase, Newark, N. J.

Special machinery designed and built; duplicate parts, tools, jigs and dies. The Wade Machine Co., 133 Oliver St., Boston.

Mechanical engineer, Cleveland, O., will represent and sell for outside firm. Commission. Box 985, AMERICAN MACHINIST.

Model making. Patented machines manufactured on royalty. Rotary File & Machine Co., 589 Kent Ave., Brooklyn, N. Y.

Wanted—Second-hand Rivett back geared 8-inch precision lathe and attachments in good condition. C. Nutter, Topeka, Kan.

Special machinery accurately built. Screw machine and turret lathe work solicited. Robert J. Emory & Co., Newark, N. J.

Inventions, novelites, ideas, etc., developed; special machines designed. Albert Pott, M. E., 23 Platt St., New York, and Waterbury, Conn.

If you have a copy of March 7, 1907 AMERICAN MACHINIST we'll give you fifteen cents for it. AMERICAN MACHINIST, 505 Pearl St., New York.

Automatic machinery designed; special purpose machines; working drawings. C. W. Pitman, 3519 Frankford Ave., Philadelphia, Pa.

Special machinery, tools, dies, jigs and fixtures designed. Ideas worked out and perfected. F. E. Huxley, 436 Jackson Boulevard, Chicago, Ill.

Wanted—Some novelty or small machine to manufacture. Will buy patent, or territory rights. Capital Foundry & Machine Co., Frankfort, Ky.

Gears cut to order, bevel, spur and mitre, on Bilgram and Gleason machines. Complete gears furnished. The Cincinnati Gear Works, Murdock Building, Cincinnati, Ohio.

Air, ammonia compressors, steam, gas, oil engines, turbines, centrifugal pumps, special machinery designed, inventions developed. Box 951, AMERICAN MACHINIST.

Special machinery designed, new ideas developed to practical results; tell me the conditions you wish to improve and I will do the rest. Box 950, AMERICAN MACHINIST.

Mechanical engineer or manufacturing man desired in my machinery and hardware business. Dividend payer. Must invest $5,000–$10,000. Box 988, AMERICAN MACHINIST.

A large English firm of machine-tool importers having showrooms and offices in Great Britain, France, Italy and Japan, is wanting good agencies for machine tools of all kinds. Apply Box 189, AMERICAN MACHINIST.

Machinery built to order and by contract; special parts made; gear cutting, automobile and pattern work, punch press and screw machine work, tools, dies, etc. Blair Tool and Machine Works, West and Morris Sts., New York City.

Special machinery and duplicate machine parts built to order; tools, jigs and experimental work; complete modern equipment. MacCordy Mfg. Co., Amsterdam, N. Y.

New British patent laws; high class engineering firm with modern plant is open to quote favorable terms for building engineering specialties or machine tools in England. The Simplex Engineering Co., Ltd., Trafford Park, Manchester.

In evenings, invent for profit; mail invention for free advice, and cost to obtain a patent; popular prices; open day and evening. Edward P. Thompson, M. E., registered patent attorney, member A. S. M. E., and A. I. E. E., 50 and 53 Morningside Ave., West, New York, via subway to Columbia University station.

Situations Wanted

Classification indicates present address of advertiser, nothing else.

CONNECTICUT

Superintendent or foreman. Successful mechanic, seven years in charge gasoline motors, general machinery tool work, designer of jigs. Cost reducer, modern methods, references. Box 987, AMERICAN MACNIHIST.

ILLINOIS

Superintendent, 38, practical mechanic, highly successful manager of men, interchangeable work, moderate salary. Box 933, AM. MACH.

Foreman toolmaker, familiar with interchangable manufacture, intricate tools and fixtures and with some experience designing special machine tools. C. H. I., AMERICAN MACHINIST.

Designer, with experience on machine tools, special machines, tools and fixtures for modern manufacture of light machinery. Competent and reliable. Box 991, AMERICAN MACHINIST.

Situation Wanted—Graduate mechanical engineer, nine years machinist on electrical, general machinery, tools and four years drafting. In or near Chicago. Box 990, AMERICAN MACH.

Foreman of automatic and hand screw machine department, eighteen years experience, desires change. Capable to design tools, cams and attachments. Will go anywhere. Box 976, AMERICAN MACHINIST.

MASSACHUSETTS

First-class metal patternmaker, experienced on hand and moulding-machine patterns, wishes position. Will go anywhere. Box 938, AM. MC.

Fine mechanic, first-class machinist, electrical instrument and apparatus maker, speedometers, any mechanical work, age 31, go anywhere. L., 185 Heath St., Roxbury, Boston.

Wanted, supervision by an active expert mechanic, a genuine cost reducer, productive and up-to-date organizer and systematizer. Address "Systematizer," AMERICAN MACHINIST.

Designer and engineer on light and heavy machinery; inventive and manufacturing development; modern shop processes; 30 years old; eight years in last position as chief, twelve years practical experience; open for responsible position April 1st. Box 963, AMERICAN MACHINIST.

MICHIGAN

Mechanical engineer, having designed a line of gasoline and producer gas engines of an improved modern type, wants to have position with concern for the manufacturing of same. Had responsible position for several years with leading German firm. First-class references. Box 983, AMERICAN MACHINIST.

NEW JERSEY

Mechanical draftsman, long experience, wishes position. Box 993, AMERICAN MACHINIST.

Chief draftsman, experienced on steam, gas, oil engines, turbines, air, ammonia compressors, centrifugal pumps, inventor and executive, wants responsible position. Box 966, AM. MACH.

Experienced, all-around practical machine shop foreman and superintendent desires position. Several years as assistant superintendent of plant, 3,000 men, has ability for handling any big proposition, and yet I am not a "know-it-all." Box 975, AMERICAN MACHINIST.

NEW YORK

Gas engine, draftsman, references, experience. Box 989, AMERICAN MACHINIST.

Mechanical draftsman, wishes position. Address, Box 992, care AMERICAN MACHINIST.

Engineer, German college education, seven years' shop and office experience, especially cranes and hoists, wants new start. Box 979, AMERICAN MACHINIST.

First-class tool and die maker wants position. Twenty-eight years' experience in large manufacturing concerns. Cutting and drawing dies preferred. Box 981, AMERICAN MACHINIST.

Chief draftsman, automatic machinery, tool and fixture experience, desires change. Expert designer, rapid, ambitious and practical. Can purchase or superintend. Box 986, AM. MACH.

OHIO

Toolmaker, machinist, twenty years varied experience, wants position. Box 980, AM. MACH.

Mechanical superintendent or general foreman desires position with a concern in northern part of Ohio where the services of a first-class man are needed. Best of references can be furnished. Address W. A. M., AMER. MACH.

PENNSYLVANIA

Draftsman and engineer, German university graduate, thoroughly familiar with general shop engineering, design of dies, tools, special machinery. A-1 reference. Box 978, AM. MACHINIST.

WISCONSIN

Wanted—Position as assistant superintendent. Technical graduate, a producer familiar with modern shop and drafting room practice. Box 982, AMERICAN MACHINIST.

Help Wanted

Classification indicates present address of advertiser, nothing else.

CANADA

Wanted, man thoroughly posted on the production capacity of machine tools to set premium time limits in large electrical establishment. Must have had experience and be systematic. Apply with references and salary wanted to Box 948, AMERICAN MACHINIST.

Superintendent, with experience in building woodworking machinery preferred, capable of taking full charge of the manufacturing, where 200 hands are employed, familiar with modern shop methods and able to produce at a minimum cost; state age, experience and salary expected with references. Address, "Canada," AM. MACH.

ILLINOIS

Wanted—Producer gas engine designer thoroughly up-to-date. Must be wide awake to possibilities and familiar with latest practice here and abroad. Give experience and salary wanted. Box 935, AMERICAN MACHINIST.

MASSACHUSETTS

Pump Doctors—Expert repair men wanted by manufacturers of trade steam, power, electric driven pumps and small engines. Box 958, AMERICAN MACHINIST.

MICHIGAN

Salesman for your state for remarkable fuel and labor saving device for boilers selling for $50. Over 20,000 in use in the U. S. and Canada. Also hardware salesman to carry as side line our wonderful newly patented spirit level. Diamond Power Specialty Co., Detroit, Mich.

NEW JERSEY

Wanted—First-class foreman of assemblers for heavy electrical machinery. State experience and expected salary. Box 974, AM. MACHINIST.

Wanted—First-class designer and originator on hydraulic work, pumping engines, air and steam machinery. Must be fully competent to work out designs, practical experience, ability to redesign, develop and improve requirements. Address with full details, Box 957, AM. MACH.

NEW YORK

Wanted—Mechanic who understands the manufacturing of tools. State experience. Address Tool, Box 977, AMERICAN MACHINIST.

For Sale

For Sale—Well equipped general machine shop in New Jersey; employing 15 to 20 hands; good reason for selling. R., Box 1216, New York City.

Good will and tools of completely equipped machine shop, centrally located in lower part of New York City. No dealers need apply. Box 949, AMERICAN MACHINIST.

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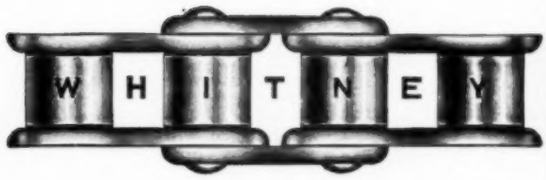

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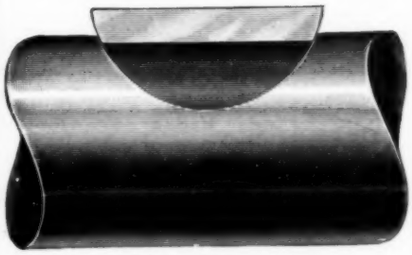

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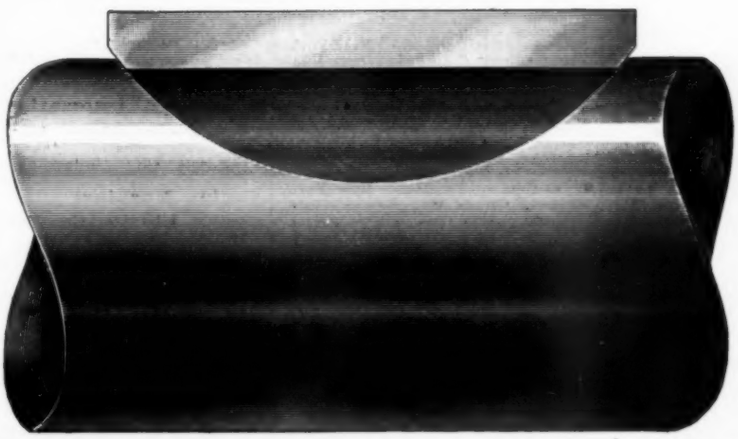

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Niles-Bement-Pond Co., New York.
Link-Belt Co., Philadelphia, Pa.

Cupolas, and Ladles, Foundry

Obermayer Co., S., Cincinnati, O.
Paxson Co., J. W., Phila., Pa.
Stevens, F. B., Detroit, Mich.

Cups and Covers, Oil

Bay State Stamping Works, Worcester, Mass.
Besly & Co., Chas. H., Chicago, Ill.
Lunkenheimer Co., Cincinnati, O.
Winkley Co., Detroit, Mich.

Cups, Grease

Lunkenheimer Co., Cincinnati, O.

Cutters, Milling

Adams Co., Dubuque, Iowa.
Becker-Brainard Milling Machine Co., Hyde Park, Mass.
Brown & Sharpe Mfg. Co., Providence, R. I.
Cleveland Twist Drill Co., Cleveland, O.
Hardinge Bros., Chicago, Ill.
Harrison & Knight Mfg. Co., Newark, N. J.
Ingersoll Milling Mach. Co., Rockford, Ill.
Morse Twist Drill & Mach. Co., New Bedford, Mass.
Pratt & Whitney Co., Hartford, Conn.
Rogers Works, Jno. M., Gloucester City, N. J.
Sloan & Chace Mfg. Co., Ltd., Newark, N. J.
Standard Tool Co., Cleveland, O.
Union Twist Drill Co., Athol, Mass.
Ward & Son, Edgar T., Boston, Mass.
Whitney Mfg Co., Hartford, Ct.

Cutting-off Machines

Armstrong Bros. Tool Co., Chicago, Ill.
Bignall & Keeler Mfg. Co., Edwardsville, Ill.
Brown & Sharpe Mfg. Co., Providence, R. I.
Davis Machine Co., W. P., Rochester, N. Y.
Hurlbut-Rogers Mach. Co., South Sudbury, Mass.
McCabe, J. J., New York.
Newton Mach. Tool Wks., Philadelphia, Pa.
Pratt & Whitney Co., Hartford, Conn.
Prentiss Tool & Supply Co., New York.
Schmitz, August, Dusseldorf, Germany.
Tindel-Morris Co., Eddystone, Pa.
Vandyck Churchill Co., New York.

Cutting-off Tools

Armstrong Bros. Tool Co., Chicago, Ill.
Billings & Spencer Co., Hartford, Conn.
Cleveland Twist Drill Co., Cleveland, O.
Fitchburg Machine Works, Fitchburg, Mass.
O. K. Tool Holder Co., Shelton, Conn.
Pratt & Whitney Co., Hartford, Conn.
Western Tool & Mfg. Co., Springfield, O.

Diamond Tools

American Emery Wheel Co., Providence, R. I.
Bridgeport Safety Emery Wheel Co., Bridgeport, Conn.
Dickinson, Thos. L., New York.
Safety Emery Wheel Co., Springfield, O.

Dies, Sheet Metal

American Tube & Stamping Co., Bridgeport, Conn.
Bliss Co., E. W., Brooklyn, N. Y.
Consolidated Press and Tool Co., Hastings, Mich.
Ferracute Mach. Co., Bridgeton, N. J.
Globe Machine & Stamping Co., Cleveland, O.
Manville Bros Co., Waterbury, Conn.

Dies, Sub-Press

Sloan & Chace Mfg. Co., Newark, N. J.

Dies, Sub-Press—*Continued.*

Waltham Machine Works, Waltham, Mass.

Dies, Threading, Opening

Errington, F A., New York.
Foote-Burt Co., Cleveland, O.
Geometric Tool Co., New Haven, Conn.
Jones & Lamson Machine Co., Springfield, Vt.
Pratt & Whitney Co., Hartford, Conn.

Dowel Pins

Winkley Co., Hartford, Conn.

Drawing Boards and Tables

Alteneder & Son, Theo., Philadelphia, Pa.
Kolesch & Co., New York.

Drawing Materials

Alteneder & Son, Theo., Philadelphia, Pa.
Kolesch & Co., New York.
Technical Supply Co., Scranton, Pa.

Drafting Machines

Universal Drafting Mach. Co., Cleveland, O.

Drilling Machines, Bench

American Watch Tool Co., Waltham, Mass.
Barnes Co., W. F. & John, Rockford, Ill.
Boynton & Plummer, Worcester, Mass.
Ingersoll-Rand Co., New York.
Pratt & Whitney Co., Hartford, Conn.
Prentice Bros. Co., Worcester, Mass.
Rockford Drilling Mach. Co., Rockford, Ill.
Slate Machine Co., Dwight, Hartford, Conn.
Sloan & Chace Mfg. Co., Ltd., Newark, N. J.
U. S. Electrical Tool Co., Cincinnati, O.

Drilling Machines, Boiler

American Tool Works Co., Cin., O.
Bickford Drill & Tool Co., Cincinnati, O.
Boynton & Plummer, Worcester, Mass.
Foote-Burt Co., The, Cleveland, O.
Ingersoll-Rand Co., New York.
McCabe, J. J., New York.
Niles-Bement-Pond Co., New York.
Prentice Bros. Co., Worcester, Mass.

Drilling Machines, Electric

Chicago Pneumatic Tool Co., Chicago, Ill.
Clark, Jr., Elec. Co., Inc., Jas., Louisville, Ky.

Drilling Machines, Multiple Spindle

American Tool Wks. Co., Cin., O.
Baker Bros., Toledo, O.
Barnes Co., W. F. & John, Rockford, Ill.
Baush Mach. Tool Co., Springfield, Mass.
Bickford Drill & Tool Co., Cincinnati, O.
Flather Planer Co., Mark, Nashua, N. H.
Foote-Burt Co., The, Cleveland, Ohio.
Fosdick Mach. Tool Co., Cin., O.
Hardinge Bros., Chicago, Ill.
Harrington, Son & Co., Edwin, Philadelphia, Pa.
Henry & Wright Mfg. Co., Hartford, Conn.
Hill, Clarke & Co., Inc., Boston, Mass.
Marshall & Huschart Machry. Co., Chicago, Ill.
McCabe, J. J., New York.
Newton Mach. Tool Works, Inc., Philadelphia, Pa.
Niles-Bement-Pond Co., New York.
Prentice Bros. Co., Worcester, Mass.
Prentiss Tool & Supply Co., New York.
Rockford Drilling Mach. Co., Rockford, Ill.
Sellers & Co., Inc., Wm., Philadelphia, Pa.
Slate Machine Co., Dwight, Hartford, Conn.
Taylor & Fenn Co., Hartford, Ct.

Drilling Machines, Portable

Cincinnati Elec. Tool Co., Cin., O.
Clark, Jr., Elec. Co., Inc., James, Louisville, Ky.

Drilling Machines, Portable—*Continued.*

Coates Clipper Mfg. Co., Worcester, Mass.
Gem Mfg. Co., Pittsburg, Pa.
Hisey-Wolf Mach. Co., Cin., O.
Ingersoll-Rand Co., New York.
Niles-Bement-Pond Co., New York.
U. S. Electrical Tool Co., Cincinnati, O.

Drilling Machines, Radial

American Tool Wks. Co., Cin., O.
Baush Mach. Tool Co., Springfield, Mass.
Bickford Drill & Tool Co., Cincinnati, O.
Dreses Mach. Tool Co., Cin., O.
Fitchburg Machine Works, Fitchburg, Mass.
Foote-Burt Co., Cleveland, O.
Fosdick Mach Tool Co., Cin., O.
Gang Co., Wm. E., Cincinnati, O.
Harrington, Son & Co., Edwin, Philadelphia, Pa.
Marshall & Huschart Machry. Co., Chicago, Ill.
McCabe, J. J., New York.
Morris Foundry Co., Jno. B., Cincinnati, O.
Mueller Mach. Tool Co., Cin., O.
Niles-Bement-Pond Co., New York.
Prentice Bros. Co., Worcester, Mass.
Prentiss Tool & Supply Co., New York.
Sellers & Co., Inc., Wm., Philadelphia, Pa.
Vandyck Churchill Co., New York.
Wormer Mchy. Co., C. C., Detroit, Mich.

Drilling Machines, Turret

Fay Machine Tool Co., Phila., Pa.
Niles-Bement-Pond Co., New York.

Drilling Machines, Upright

American Tool Wks. Co., Cin., O.
Baker Bros., Toledo, O.
Barnes Co., W. F. & John, Rockford, Ill.
Beaman & Smith Co., Prov., R. I.
Boynton & Plummer, Worcester, Mass.
Cincinnati Mach. Tool Co., Cincinnati, O.
Clark, Jr., Elec. Co., Inc., Jas., Louisville, Ky.
Davis Machine Co., W. P., Rochester, N. Y.
Fosdick Mach. Tool Co., Cin., O.
Foote-Burt Co., Cleveland, O.
Gould & Eberhardt, Newark, N. J.
Harrington, Son & Co., Edwin, Philadelphia, Pa.
Henry & Wright Mfg. Co., Hartford, Conn.
Hill, Clarke & Co., Inc., Boston, Mass.
Hoefer Mfg. Co., Freeport, Ill.
Kern Machine Tool Co., Cincinnati, O.
Knight Machry. Co., W. B., St. Louis, Mo.
Marshall & Huschart Machry. Co., Chicago, Ill.
McCabe, J. J., New York.
Mechanics Machine Co., Rockford, Ill.
Morse Twist Drill & Mach. Co., New Bedford, Mass.
New Haven Mfg. Co., New Haven, Conn.
Niles-Bement-Pond Co., New York.
Prentice Bros. Co., Worcester, Mass.
Prentiss Tool & Supply Co., New York.
Rockford Drilling Mach. Co., Rockford, Ill.
Sellers & Co., Inc., Wm., Philadelphia, Pa.
Sibley Machine Tool Co., South Bend, Ind.
Slate Machine Co., Dwight, Hartford, Conn.
Sloan & Chace Mfg. Co., Newark, N. J.
Taylor & Fenn Co., Hartford, Conn.
Vandyck Churchill Co., New York.
Whitney Mfg. Co., Hartford, Ct.
Wiley & Russell Mfg. Co., Greenfield, Mass.
Wormer Mchry. Co., C. C., Detroit, Mich.

Drills, Center

Cleveland Twist Drill Co., Cleveland, O.
Morse Twist Drill & Machine Co., New Bedford, Mass.
Pratt & Whitney Co., Hartford, Conn.
Slocomb Co., J. T., Prov., R. I.
Standard Tool Co., Cleveland, O.